IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received 19 July 2024, accepted 10 August 2024, date of publication 15 August 2024, date of current version 26 August 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3443990

SURVEY

Survey on Clustered Routing Protocols Adaptivity for Fire Incidents: Architecture Challenges, Data Losing, and Recommended Solutions

OLA KHUDHAIR ABBAS[1,2], FAIRUZ ABDULLAH[1], (Senior Member, IEEE), NURUL ASYIKIN MOHAMED RADZI[1], (Senior Member, IEEE), AYMEN DAWOOD SALMAN[3], AND SAID JADID ABDULKADIR[4,5], (Senior Member, IEEE)

[1]Institute of Power Engineering, Universiti Tenaga Nasional (UNITEN), Kajang, Selangor 43000, Malaysia
[2]General Directorate of Education in Misan Governorate, Iraqi Ministry of Education, Misan 10045, Iraq
[3]Department of Computer Engineering, University of Technology–Iraq, Baghdad 10066, Iraq
[4]Department of Computer and Information Sciences, Universiti Teknologi PETRONAS, Seri Iskandar 32610, Malaysia
[5]Centre for Research in Data Science, Universiti Teknologi PETRONAS, Seri Iskandar 32610, Malaysia

Corresponding author: Ola Khudhair Abbas (pe21127@student.uniten.edu.my)

This work was supported in part by the Ministry of Higher Education (MOHE), Malaysia, through the Fundamental Research Grant Scheme under Grant FRGS/1/2022/ICT02/UTP/02/4; and in part by Universiti Teknologi PETRONAS through the Yayasan Universiti Teknologi PETRONAS under Grant YUTP-FRG/015LC0-521.

ABSTRACT Wireless Sensor Networks (WSNs) significantly impact reliable data communications in environmental monitoring, health care, and transportation applications. Low-powered and small sensor nodes compose these networks, configured to perform specific tasks like detection, management, prediction, and monitoring. Clustering in WSNs is a reliable method of effectively transferring data within the network through routing. Thus, developing an effective routing algorithm to optimize network functionality is a big concern. Cluster Heads (CHs), selected through a range of metrics, are responsible for data aggregation and transmission to the Base Station (BS). Many clustered routing algorithms have been developed to address various issues like energy efficiency, network lifetime, and hotspot problems. However, several challenges still need to be addressed, including network segmentation, isolated node issues, and data routing failures. This survey offers a comprehensive review of various routing protocols and their different performance metrics. It evaluates the architectural challenges that caused network segmentations and data routing failures in the case of unexpected head node failures during high-stress events, particularly indoor fires. Recommended solutions to the mentioned issues are also explored. A new taxonomy for the CH-selection methods based on the technique used is proposed, along with a comparative review of other CH-selection surveys. Additionally, this survey scrutinizes the challenges and constraints inherent in current fault tolerance routing algorithms, evaluating their efficacy in fire-related incidents. The survey concluded that protocol designers must focus on the development and implementation of fire-adaptive routing protocols, incorporating optimal fault tolerance routing algorithms that adapt seamlessly to unforeseen environmental changes, including fire incidents. Such adaptability is pivotal in preserving network topology and preventing data loss.

INDEX TERMS Wireless sensor network, routing protocols, hierarchical clustering, network segmentation, data routing failure, architecture challenges, fault tolerance.

I. INTRODUCTION

Wireless sensor Network (WSN) applications are growing rapidly in different domains, and within the last few years,

The associate editor coordinating the review of this manuscript and approving it for publication was Salekul Islam.

they have gained significant attention due to their ability to acquire data from distant or inaccessible sites. WSN is composed of a massive number of battery-dependent sensor nodes, that acquire environmental data for utilization in numerous applications.

Diverse sensor types could be used in WSNs, such as temperature, light density, radiation, gas levels, humidity, and flame sensors. These nodes are deployed in a physical region and use wireless links to communicate with each other. They can perform assigned tasks in terms of environmental monitoring, security, surveillance, home automation, attack detection, smart grids, and traffic management [1], [2] [3]. WSNs must be capable of providing low-cost, reliable, and secure control and communication capabilities. The sensors in WSN use multi-hopping in the long-range transmission of large monitoring areas to maintain their scalability and flexibility attributes. A sensor node is a small device that senses data and submits the information to the base station (BS) directly or through mediator nodes. Usually, normal sensor nodes have energy constraints, while the BS is different and more robust than other nodes due to its large processing capabilities and high storage ability with a rechargeable battery [4], [5].

WSNs can be classified as homogeneous, based on the diversity of the communication mediums, sensing levels, and capabilities. In homogeneous networks, all nodes have the same set of algorithms and routing rules to facilitate the data forwarding within the network. The nodes in homogeneous WSNs have identical energy, communication links, and sensing levels. In contrast, a heterogeneous WSN comprises two or more distinct types of nodes with different capabilities. Homogeneous WSNs have been designed for different applications, due to their simplicity, ease of deployment, scalability, lower cost, and reduced communication overhead. However, heterogeneous WSNs are more convenient for real-world situations because of their adaptivity to real-world conditions where various sensing types need to be measured utilizing various energy levels and communication links [6], [7], [8].

Hierarchical routing protocols are a type of routing protocol that is composed of several clusters; each cluster has a distinctive node called a Cluster Head (CH). The CH is accountable for data collection from the cluster members and then performs the aggregation and transmission to the BS [9]. Extensive studies on routing protocols were directed at the effectiveness of hierarchical routing protocols in terms of prolonging network lifetimes and reducing energy consumption [10].

Routing protocols research is categorized according to various levels, constraints, and attributes. One major constraint for WSNs is energy usage. Thus, several routing protocol studies have investigated the energy constraint issue for WSNs [11]. Furthermore, various WSN aspects have been handled by the routing protocol developers, such as memory storage efficiency, fault tolerance, and throughput [12], [13]. Various surveys on clustering and routing algorithms have addressed efficient power usage, reliability, scalability, security, and self-organization discussed many techniques utilized to improve the network's performance [14], [15]. However, different challenges in routing algorithms need to be addressed, including network segmentation and unexpected head node losses that cause data routing failure. One of the key aspects that must be considered is adaptivity, where the routing algorithm dynamically makes routing decisions based on the network conditions so that the algorithms build the routing table depending on the network topology and traffic. Therefore, routing algorithms utilized in WSNs must be adaptable enough to accommodate frequent cluster changes [16], [17]. Moreover, the unreliable network environment influences WSN performance. Hence, specific sensor nodes could be unreliable due to physical damage, malfunctions, or a lack of energy. Routing algorithms should ideally be able to reorganize themselves around dead or unreliable nodes [18], [19].

Fire incidents pose major hazards to individuals, property, and the surrounding environment. It can pose a significant risk to human life, causing fatalities, injuries, burns, or long-term health effects due to smoke inhalation. The long-term environmental effects of fires can include biodiversity loss, habitat devastation, and pollution of the air and water. Fire hazards provide unique challenges that require specialized schemes in routing protocols to develop to overcome the dynamic and life-threatening nature of fire emergencies. Unlike some natural catastrophes that primarily influence the outdoors including earthquakes, hurricanes, and floods, fires may occur indoors, where communication networks are frequently more densely deployed and where routing protocols must navigate complex structures and obstacles. In addition, fires may significantly damage buildings, causing economic impacts, and can spread rapidly, changing the topology of indoor environments within minutes. Therefore, when a fire spreads in a building, it may cause malformations in the installed network. Thus, during a fire, the sensing devices will often be disconnected from the network or indeed destroyed, leading to network segmentation and data routing failures. This may lead to the loss of monitored data where the firefighter can rely on timely conditions—i.e., temperature—updates to remain aware of fire progress [20], [21]. Furthermore, according to the International Association of Fire and Rescue Services (CTIF), there were 315,142 fire injuries and 136,701 fire deaths worldwide between 2017 and 2021. Throughout the same period, there were 418 firefighter deaths and 323,367 firefighter injuries worldwide. Moreover, in 2021, residential buildings accounted for 84.6% of all fire deaths worldwide and 6.0% for other buildings. On the other hand, residential buildings accounted for 73.7% of all fire injuries and 9.8% for other buildings [22]. Hence, fire incidents are considered a special case for general incidents because of the rapidly changing network topology, hazardous environmental conditions, urgent and critical communication needs, unique sensor requirements, and high node failure rate. Accordingly, designing routing protocols specifically tailored for indoor fire hazards is crucial due to the unique challenges posed by fires and their significant impact on communication networks and overall safety. Traditional routing protocols may not adapt quickly enough to these dynamic changes.

This paper offers a comprehensive examination of diverse routing algorithms and their impact on enhancing the performance of WSNs during indoor fire incidents that lead to the failure of nodes. While prior survey papers have covered routing algorithms, they often overlooked critical aspects such as data routing failure during these events and the adaptability of algorithms to network segmentation. Further elaboration on gaps will be discussed in Section VII. This survey conducted an extensive review of routing protocols' adaptivity to fire incidents. It thoroughly reviewed a wide range of research using various application scenarios, methodologies, and performance metrics. The following key aspects demonstrate the comprehensiveness of this analysis: The survey reviewed over 84 studies from relevant resources, resulting in a wide spectrum of perspectives and findings. It makes detailed comparisons among routing protocols to assess their adaptability to fire events and evaluates novel parameters such as network segmentation, cluster insulation, data loss, routing failure, and limitations in fire incidents. It presents an in-depth discussion and analysis of their strengths and limitations in the context of fire incidents, as well as their contributions and methodology. Further, this survey identified the primary architecture challenges faced by current routing protocols when exposed to fire incidents. These involve issues with real-time adaptation, network segmentation, and data loss. Based on the identified challenges, the survey discussed various proposed innovative techniques and solutions from the literature. It further suggested potential future research directions to handle the gaps and enhance the routing protocols' adaptability to fire incidents.

The main objective of this article is to investigate whether the routing protocols are capable of functioning effectively in the event of the sudden loss or unexpected death of the high-energy head nodes in fire incidents, which will result in the dropping of acquired data and prohibit data delivery to the sink node. To the best of our knowledge, this is the first survey that discusses the routing protocols' adaptivity to fire incidents regarding the main nodes' isolation, network segmentation, and data routing failures. Analysis of the architecture challenges for the reviewed algorithms and the recommended solution were discussed. A new CH selection taxonomy and inclusive comparison for the recent CH selection surveys were also introduced. In addition, the challenges and limitations of fault-tolerance routing algorithms were presented. The list of acronyms and the conceptual structure of the survey are expressed in Table 1 and Fig.1, respectively. The contributions to this survey are as follows:

- Summarize an inclusive review of hierarchical routing protocols in terms of energy efficiency, data routing, data transmission, BS location, scalability level, node mobility, hierarchical level,, and topology.
- Provide a detailed valuation for the reviewed routing protocols regarding contributions, strengths, and limitations.
- Introduce an analytical assessment of three of the architectural challenges that prevent the effective functioning of the routing algorithm in unforeseen incidents that cause network segmentation and accordingly overthrow monitored data.
- Assign recommended directives that would help to get rid of the three challenges encountered in the data routing process during fires.
- Develop a new classification for the CH selection methods based on the utilized techniques and introduce an inclusive comparison with the state-of-the-art CH selection surveys.
- Present a critical evaluation of the challenges and limitations of the current fault tolerance routing algorithms to assess their effectiveness in fire incidents.

This paper is organized as follows: Section II contains the survey's motivations and key innovations. Section III describes the classification of routing protocols. Routing challenges and design issues in routing protocols are explained in Section IV. Section V discusses the metrics for the performance evaluation of routing protocols. Section VI presents the related work. Section VII explains the analysis of the architecture challenges for the routing protocols in fire incidents. Section VIII discusses the recommended future direction. Section IX describes a new classification for the CH selection method based on the used technique. Section X presents the limitations and challenges of the fault tolerance routing algorithms. Section XI highlights the conclusion of this survey and future recommendations.

II. SURVEY MOTIVATION

A survey is usually important in providing the proper knowledge and key aspects of any field, including clustering and routing protocol approaches. It may assist researchers in acquiring an acceptable perception, conducting a comprehensive review of routing algorithms, and covering the major aspects of clustering in routing protocols.

Many algorithms were presented for the clustering domain, providing professional services to manage network challenges and attempt to improve network performance. The key objectives of routing protocols were to ensure data routing and Quality of Service (QoS), as well as extend network longevity [23], [24], [25], [26].

The major motivation for this survey is to introduce a synopsis of various routing protocols to the researchers, and, based on network architecture and methodology, to verify if these protocols prevent cluster insulation, data routing failure, and network segmentation in unexpected indoor fires. Various survey papers on cluster-based routing protocols

TABLE 1. List of acronyms and definitions.

Acronyms	Definitions
ADV	Advertisement
AI	Artificial Intelligence
ASLPR	Application Specific Low Power Routing Protocol
BEST-MAC	Bitmap Assisted Efficient and Scalable Time Division Multiple Access-based Media Access Control
BKCH	Backup Cluster Head
BRO	Battle Royale Optimization Algorithm
CNN	Convolution Neural Network
DUCF	Distributed Load Balancing-Unequal Clustering Using Fuzzy
EDFCM	Energy Dissipation Forecast and Clustering Management
FANET	Flying Ad-hoc Network
FTRA	Fault Tolerance Routing Algorithms
GA	Genetic Algorithm
GATERP	GA-Based Threshold-Sensitive Energy-Efficient Routing Protocol
HSA	Harmony Search Algorithm
IoMT	Internet of Medical Things
ISFO	Improved Sunflower Optimization
LDPC	Low-Density Parity-Check
LEACH	Low Energy Adaptive Clustering Hierarchy
LSTM	Long Short-Term Memory
MDC	Mobile Data Collector
MGN	Multiple Gateway Node
MLRC	Multi-Level Route-Aware Clustering
NRA	Node Rank Algorithm
PASCCC	Priority-Based Application-Specific Congestion Control Clustering Protocol
PSO	Particle Swarm Optimization
QoS	Quality of Service
RS	Reed Solomon
RSSI	Received Signal Strength Indication
SBHRA	Section-Based Hybrid Routing Protocol with Artificial Bee Colony
SCHFTL	Super Cluster Head Election Using Fuzzy Logic in Three Levels
TDMA	Time Division Multiple Access
TEO	Thermal Exchange Optimization

were published. However, they failed to mention the data routing failure issue in sudden incidents and the algorithm's adaptivity to network segmentation.

The clustering schemes are categorized into four classifications, which are: homogeneous networks, heterogeneous networks, fuzzy logic, and heuristic-based protocols based on network organization and the techniques utilized to control the clustering procedures [27]. Various performance parameters to evaluate the four types are considered, along with the objectives, limitations, and advantages.

The Low Energy Adaptive Clustering Hierarchy (LEACH) descendant clustering algorithms are classified based on CH selection and data transmission [28]. Various metrics, such as scalability, CH selection, communication method, mobility, energy efficiency, and node localization are considered for protocol evaluation. In addition, the strengths and limitations of LEACH-variant protocols were also discussed. Adnan et al. provided an inclusive review of clustering algorithms [29]. Different clustering algorithm topics are discussed in this review in terms of characteristics, CH selection methods, objectives, and challenges. In addition, it provided a detailed review of the new methods proposed to handle energy heterogeneity and harvesting, mobility, fault tolerance, and scalability in WSNs. A systematic review of traditional and state-of-the-art clustering methods for different domains is present [30]. It shows the prominent role of clustering in various fields, such as medicine, education, biology, and marketing. It also discusses the application of clustering in big data, artificial intelligence, and robotics.

Diverse clustering methods and cluster-oriented protocols were reviewed [31]. It defines clustering as a significant option for decreasing energy consumption. Various features, such as cluster formation, CH selection, security, routing, dependability, and unequal clustering were all addressed. Different approaches are categorized based on classic, optimization, and machine learning schemes.

Table 2 introduces a comparison between the recent clustering surveys and the proposed one. While there are many existing surveys on the routing protocol, our survey offers a distinct perspective by concentrating on routing protocol adaptivity to fire incidents. This is a significant aspect that hasn't been adequately investigated in prior research. Expanding on current knowledge is essential, and that is precisely what our study accomplishes by assessing the most recent advances in routing protocols and their adaptability to fire incidents, an area continuously evolving. Accordingly, the survey innovations that differentiate it from related surveys can be highlighted as follows:

- As numerous studies have been conducted on routing protocols in general, this survey specifically emphasizes the adaptivity of these protocols to fire emergencies. This narrowed emphasis enables a more thorough and relevant analysis of scenarios involving fire incidents, which is a substantial but little-studied field.
- In addition to reviewing current routing methods, this survey offers an in-depth assessment of the unique challenges caused by fire accidents, including data loss, network segmentation, and real-time adaptation. Subsequently, it goes into specific solutions that have been brought out in the literature to deal with these challenges, providing a thorough insight that is not typically obtained in broader surveys.
- We have incorporated new developments and state-of-the-art studies that were maybe not included in previous surveys. This guarantees that this survey offers the most recent developments and trends in the field.
- Our investigation shows that, to the best of our knowledge, this survey is the first to analyze the architectural challenges that routing algorithms suffer in unanticipated indoor fires.
- This survey provides a novel taxonomy for cluster head selection methods based on the techniques used, as elaborated in Section IX.

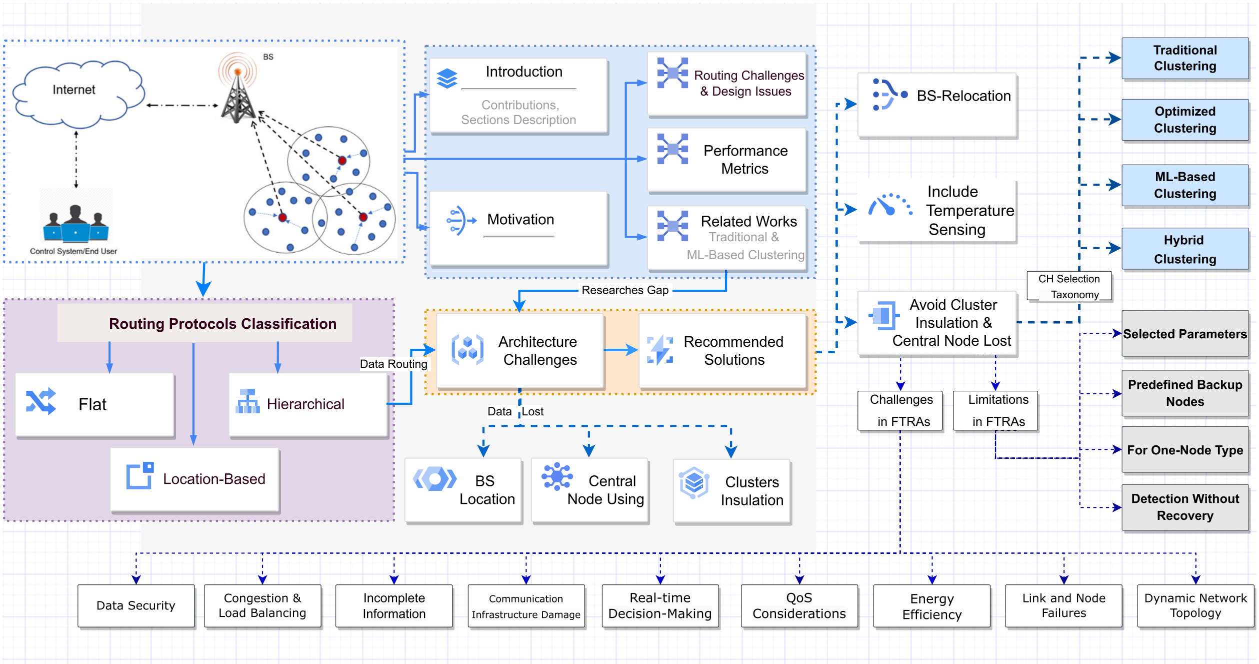

FIGURE 1. Conceptual structure for the survey.

- Even fault-tolerance routing protocols are usually developed for node-failure handling, but Section X ensures the limitations of such protocols during fire incidents. To the best of our knowledge, this survey is the first to assess the limitations of the existing fault tolerance routing algorithms during fire incidents.

III. CLASSIFICATION OF ROUTING PROTOCOLS

A well-developed routing protocol is required to build a reliable WSN and enhance network performance. Routing protocols could well be divided based on the network structure into three distinct categories listed below [32], [33], [34]:

a) **Flat Routing Protocols**: Sensor nodes have identical functionality in data collection, capabilities, transmission, and power exhaustion.
b) **Hierarchical Routing Protocols**: Sensor nodes are organized into clusters. Based on various well-known criteria, the node with the highest energy level is often chosen as the cluster head in each cluster.
c) **Location-based Routing Protocols**: Sensor nodes deliver data to specific locations using geographical information. As a result, sensor nodes must be capable of locating themselves, or their location should be calculable.

Hierarchical routing algorithms are the most common choice for Internet of Things (IoT) sensor networks [35], [36]. Clustering is used in hierarchical routing algorithms where the sensor nodes are divided into cluster groups. It is a popular data communication technique for reducing energy consumption. Hierarchical clustering divides the whole sensor network into several groups or layers. Each cluster head coordinates the transmission inside a cluster, which is further responsible for connectivity between clusters or base stations [37], [38]. Traveling data through the levels achieves network reliability for large distances and improves energy efficiency and data communication acceleration. Hence, clustering facilitates data aggregation advantages throughout cluster heads at various levels and improves overall WSN performance [39]. Hierarchical routing protocols could also be categorized into the following main classifications: 1) chain-based, 2) tree-based, 3) grid-based, and 4) area-based routing, as illustrated in Fig.2 [40].

IV. ROUTING CHALLENGES AND DESIGN ISSUES IN ROUTING PROTOCOLS

There are distinct parameters that provide challenges in routing protocol construction. Overcoming these challenges results in efficient communication, enhances network performance, and maintains network reliability. They are [41], [42], and [43]:

- **Node deployment**: Node deployment could be either deterministic or randomized. For connectivity and energy-efficient network functioning, optimum clustering is required if the resulting node distribution is not uniform.
- **Energy consumption**: Battery power shows a significant effect on sensor node longevity. The sensor node's power failure could cause major topological changes and might require network reorganization and packet rerouting. Routing protocols should reduce energy consumption by reducing overhead and optimizing path selection.

TABLE 2. Comparison with the recent reviews for WSN's clustering algorithms.

Ref./Year	Survey Scope	Contributions	Recommendations
Rawat *et al.* [27] 2021	A comparative review of general clustering algorithms	• Classifying clustering protocols based on methodologies, workings, and network organization. • Evaluation and analysis of different approaches. • Thorough assessment of clustering parameters.	• Develop application-specific protocols. • Minimize complexity and delay in protocols. • Develop heuristic and fuzzy-based protocols. • Use effective parameters for CH and relay node selection. • Focus on scalability in routing protocol development.
Daanoune *et al.* [28] 2021	A comparative analysis of LEACH descendant clustering algorithms	• Classify of LEACH clustering routing protocols. • Comparison based on energy efficiency, deployment, etc. • Comparative study with previous surveys.	• Minimize energy consumption in clustered protocols. • Consider metrics like connectivity, energy, and coverage in node deployment. • Develop fault tolerance routing protocols. • Implement coding techniques in LEACH protocols. • Focus on hybrid protocols for security and QoS.
Al-Sulaifanie *et al.* [29] 2022	A comparative review of general clustering algorithms	• Summarizing many clustering algorithms with their limitations and attributes. • Categorize CH-selection methods and studying their metrics and limitations. • The features and challenges of mobile WSNs are discussed. • Algorithms for data correlation and compression are outlined and categorized. • Stated and discussed the proposed fault tolerance algorithms.	• Achieve an optimal number of evenly distributed clusters in the CH selection method. • Ensure even distribution of energy load among nodes. • Minimizes communication and computation overhead while increasing scalability. • Focus on fault detection and recovery in the network. • Avoid collecting and transmitting redundant data.
Ezugwu *et al.* [30] 2022	Comparative survey of traditional and machine learning clustering algorithms	• Provides a systematic review of traditional and modern clustering methods. • Discuss the architecture and classification of the reviewed clustering algorithms. • Discuss open research issues related to clustering problems. • Defined future research directions regarding the development of clustering algorithms.	• Develop techniques that could extract features from big data sets, such as parallel evolutionary algorithms and distributed clustering. • Integrate domain-based requirements for a new single algorithm. • Investigate the application of hybrid clustering algorithms. • Clustering algorithms should incorporate machine learning techniques to achieve high performance.
Gunjal *et al.* [31] 2023	A comparative review of general clustering algorithms	• Clustering analysis based on different strategies, environments, and features. • Discussed energy-efficient clustering techniques. • Classify the CH selection methods. • Machine learning clustering methods are discussed along with their limitations, advantages, and applications.	• Utilize efficient CH selection methods to overcome coverage, hot spot, and energy hole issues. • Utilize machine learning methods in the case of big data processing. • Give attention to load balancing, security, scalability, and energy efficiency when developing a clustering algorithm.
This survey 2024	Analytic review of clustering routing algorithms' adaptivity to fire incidents	• Inclusive review of clustering protocols based on various performance metrics, limitations, advantages, and contributions. • Introduce an analytical assessment of the architectural challenges in fire incidents for clustered routing algorithms and discuss the recommended solutions. • Classify the CH selection methods based on the utilized techniques. • Present a critical evaluation of the CH selection methods and fault tolerance routing algorithms to assess their effectiveness in fire incidents. • Discuss the challenges and limitations of Fault Tolerance Routing Algorithms (FTRAs) in fire incidents.	• Develop a fire-adaptive clustering scheme that guarantees data delivery even with the sudden loss of head nodes. • Adopt decision-based algorithms to solve the routing hole problem and prevent packet loss. • Design an optimum fault tolerance routing algorithm adaptive to the network's changing topology. • Employ a hybrid technique for CH selection to enhance WSN performance.

- **Configuration of data reporting**: The data reporting is application-dependent and could be categorized into approaches that are time-driven, query-driven, event-driven, or a combination of all of these. The data reporting technique has a significant impact on routing protocols in terms of energy usage and route computations.
- **Node/link heterogeneity**: In many studies, routing protocols are assumed to be homogenous, where they have equal capabilities in terms of energy, communication links, sensing levels, and computations. However, homogeneity cannot satisfy real-world conditions, where a diverse mixture of sensors with different functionalities is required.
- **Scalability**: Any routing approach should be scalable enough to work with a massive number of sensors. Most of the sensors are in sleep mode, where data is collected from the remaining sensors, thus rotating the functionality based on the time slots. Protocols must be scalable to the size of the network, preserving dependability and performance without being excessively complex.
- **Fault-tolerance**: Insufficient power, physical harm, or interference from the environment might cause some sensor nodes to fail or get blocked. The data routing

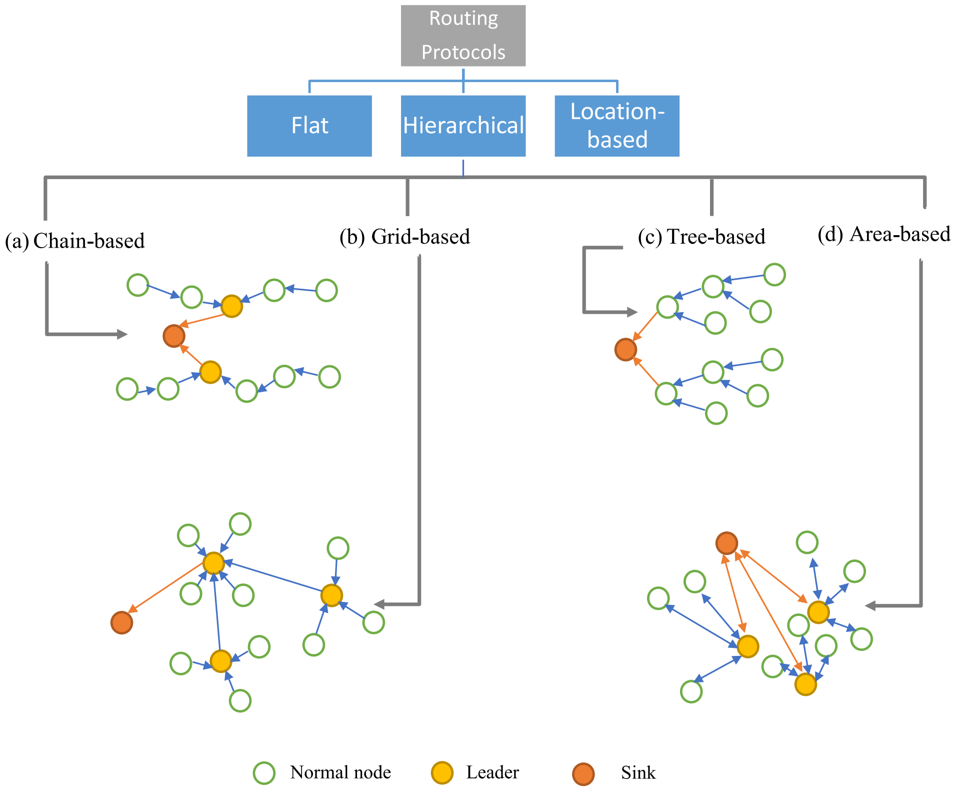

FIGURE 2. Routing protocols taxonomy with hierarchical routing categories illustration.

should not be impacted by sensor node failures. If a node fails, the algorithm must achieve packet rerouting through network regions where more energy is available. Consequently, in fault-tolerant routing protocols, multiple levels of redundancy might be needed.

- **Coverage area**: The sensor node has a specific view of the environment. Thus, it could cover only a limited physical field. Routing protocols ought to consider the geographical distribution of nodes and choose routes that prevent coverage gaps and preserve network connectivity.
- **Congestion**: Congestion-aware routing offers the best route for delivering the packet to the destination by considering the congestion status of nearby nodes, nodes in a specific area, or all nodes in the network. Congestion-adaptive routing schemes decide the packet route in terms of the network status.
- **Security**:Sensor nodes exist in an open environment; thus, security is still a primary concern for routing protocols. Also, the nodes have limited resources, so it is possible that typical cryptographic approaches cannot be employed to secure data transfer in WSNs. Hence, an authentication technique is required for secure network communication.
- **Data aggregation**: Since sensor nodes might produce a lot of redundant data, it is possible to aggregate comparable packets from different nodes to minimize the number of transmissions. This method has been used in a variety of routing protocols to optimize data transfer and achieve energy efficiency.
- **QoS policies**: In certain applications, data must be delivered within a predetermined time from the instant it is sensed, or it might be useless. Consequently, data delivery with limited latency is a further requirement for time-constrained applications.

Furthermore, there are many open issues related to routing protocols; the most significant are listed below [44], [45], [46]:

- **Large streaming applications**: Routing protocol development still requires significant attention to the design of QoS routing protocols in an energy-constrained environment for real-time implementations and multimedia services. In such applications, a huge amount of data needs to be transmitted. Hence, reliable communication and routing strategies are needed to support the massive amounts of data transmitted.
- **Mobility**: While mobility could create a dynamic network, the routing protocol's ability to manage SN's mobility is still limited. Assumptions concerning static sinks and sensor nodes are not real-world scenarios. Military surveillance administration, battlefield target tracking, and intrusion detection services all require mobility to manage sensor nodes and sink movement.

- **Mathematical model**: The simulation work must be enhanced through mathematical modeling to provide a broader view of the protocol and conduct a reliable comparison of the principal protocols. Accordingly, mathematical modeling is a field of interest that needs to be addressed in the development of routing protocols.
- **Real testbed**: One of the biggest challenges in the routing protocols is the implementation of real testbeds or hardware. The design of a routing protocol using simulation software may not exclude key features of the algorithm that could be tested more extensively on a real platform. Furthermore, hardware may impose constraints on specific parameters that cannot be tested on a simulator. However, the hardware platform's cost is a concern.
- **Network segmentation and data routing failure**: Many factors might cause this, including network congestion, security threats, software problems, physical connection failures, configuration issues, congestion on the network, and unexpected network partitioning. These issues cause degradation of data flow within networks. Addressing this issue requires robust routing protocol development that can effectively manage diverse network environments, adapt to changing network conditions, and provide mechanisms for fault-tolerance routing.

V. METRICS FOR ROUTING PROTOCOL PERFORMANCE EVALUATION

To evaluate the performance of routing protocols, various metrics are often used. The parameters are set to provide an accurate analysis of the performance specifications of the routing protocols [47]. As shown in Fig. 3, the popular metrics to evaluate routing protocol performance are [48], [49], and [50]:

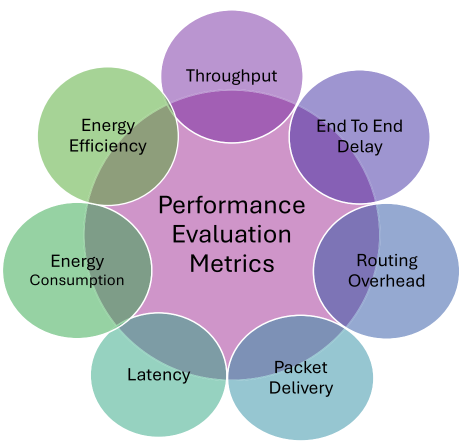

FIGURE 3. Performance evaluation metrics in routing protocols.

a) *Throughput*: Calculated in bits transmitted per second (bps). This metric provides an overview of system activities' productivity. It is a measure of routing effectiveness; therefore, higher throughput indicates that the framework maintained good performance.
b) *End-to-End Delay*: A period required to transmit data packets from source to destination.
c) *Routing Overhead*: Ratio of routing control packets transmitted by all the nodes to the received data packet at the destination.
d) *Delivery Ratio*: A percentage measure for the number of received packets in the destination divided by the number of transmitted packets.
e) *Latency*: Time delay throughout data transmission from source to destination. Measured in seconds.
f) *Energy Consumption*: Total consumed energy by the nodes during operation in Joules (J).
g) *Energy Efficiency*: Percentage in Kilobits/J, the entire number of packets delivered to the destination node from the total energy used by sensor nodes.

VI. RELATED WORK

In this section, various routing protocols will be reviewed. The comparison between the routing algorithms in terms of various performance metrics as well as contributions, strengths, and limitations will be illustrated in Table 3 and 4, respectively. Then, the reviewed routing protocols' adaptivity to sudden fire incidents will be investigated.

The literature on routing protocols is divided into two categories: traditional routing protocols where the routing algorithms apply classic routing approaches and AI-based routing protocols where various artificially intelligent methods are used for clustering and routing purposes.

A. TRADITIONAL ROUTING PROTOCOLS

Daanoune et al. proposed an adaptive coding routing algorithm for reliable WSNs and an energy-efficient routing protocol [51]. The designed algorithm enhances CH selection, cluster generation, and data communication. It selects CHs based on nodes' residual energy. Nodes use Received Signal Strength Indication (RSSI) to join a CH during the cluster's formation phase, and those that are unable to do so are considered Abandoned Nodes (AN). Simulation results indicate that the proposed protocol optimizes energy usage, network lifetime, throughput, and stability compared to other protocols. The protocol is designed for adaptive coding but not for real-time monitoring applications.

An adaptive hierarchical clustering-based routing algorithm was developed by Han et al. to ensure continuous coverage of the target area through distribution adjustment of the data transmission [52]. To balance the energy consumed by nodes, a hierarchical clustering-based routing scheme is first presented. The node number of the energy-harvesting phase is then adaptively controlled via a distributed alternation of the working modes, which has the potential to maintain target coverage. However, the effect of different environmental conditions on the efficiency of energy harvesting was not addressed.

A new Lie Hypergraph-based Routing Protocol (LHRP) for environmental monitoring in WSNs was introduced [53]. The protocol emphasizes energy efficiency and uses the lie algebra of upper triangular matrices with a hypergraph for routing and clustering purposes. The cluster head selection and routing decision archives use minimum hypergraph transversal and the Lie commutators of the upper triangular matrix, respectively. It achieves good outperformance in terms of energy consumption, the number of packets received at the base station, and the number of live nodes. A Flying Ad-hoc Network (FANET) optimized LEACH protocol has been introduced by Bharany et al. [54]. The suggested technique reduces the energy used for the transmission of data in the routing algorithm while simultaneously increasing network lifetime by maximizing node residual energy. An Analog-to-Digital Converter (ADC) is included in the sensing unit to convert analog signals into numerical values. In addition, a treatment unit is employed to enable communication between nodes. The protocol for FANET is usually used for military applications and not for indoor monitoring.

Inam et al. investigated a study on how node density and speed affect the performance of routing protocols in firefighting applications [55]. Mobile ad hoc networks were utilized for rescue applications and disaster response. Two routing protocols are designed, which are Optimized Link State Routing (OLSR) and Order Routing Algorithm (TORA). In highly mobile networks, the OLSR protocol performs better than TORA for distinct network densities.

An Internet of Things-based WSN framework for forest fire monitoring was developed [56], named the Energy-Efficient Routing Protocol (EERP). The proposed EERP approach minimizes energy consumption in sensor nodes and extends the lifetime of the IoT-WSN by reducing idle listening, submitting only pertinent data, and avoiding low-energy sensor nodes from being cluster heads. An enhanced version of the Multi-Hop Gateway-Based Energy-Aware Routing (MGEAR) protocol is presented by Benelhouri et al. to increase throughput and network longevity in heterogeneous WSNs [57]. Simulation findings show that, in both 2-level and 3-level heterogeneity scenarios, the proposed technique outperforms existing protocols in terms of throughput and increases network longevity. For heterogeneous sensor networks, an enhanced clustering technique with switchable data transmission status was proposed [58]. When the observed information intensity reaches the defined threshold, cluster heads establish a data transmission channel, filter the information being transmitted, and deliver the data to the sink. Otherwise, CHs continue to receive data supplied by the cluster nodes and record it. This algorithm does not need to pre-set the location information of nodes, so it is preferable for large-scale networks. However, the protocol's performance needs to be evaluated under various deployment scenarios and network conditions.

An Energy-Enhanced Threshold Routing Protocol (ETH-LEACH) has been proposed to overcome the traditional LEACH protocol's limitations and enhance energy efficiency and network longevity [59]. In comparison to other routing protocols, ETH-LEACH uses TDMA for opportunistic route estimation and determines a threshold value for forwarder node selection. This results in lower energy consumption and better performance. Ismaila et al. implemented an Energy-Efficient Routing Protocol-based Dijkstra algorithm (EERP-DA) to optimize the energy usage of WSNs [60]. Reducing total energy consumption and extending the network's lifetime are the main objectives. The suggested approach determines the shortest routes between the base station and the cluster head by considering several variables, including the degree of nearby CH, distance, and energy consumption. The proposed approach performs better in terms of data transfer as compared to other approaches.

Jibreel et al. suggested a routing method based on the addition of heterogeneous nodes, selection of the CHs based on residual energy, implementation of a multi-hop communication scheme in all network areas, and the use of the energy-hole elimination approach [61]. The suggested routing strategy exceeds the comparative heterogeneous protocols. However, an unforeseen loss of head nodes or gateways leads to data loss. A new application scenario for WSNs' raw data collection without redundant sensor nodes using a multi-hop network was developed [62]. The proposed protocol, which is named a hybrid tree-based and cluster-based routing protocol for raw data collection (HTC-RDC), enhances the WSNs' lifetime and achieves an improvement of 11.4% for the average network lifetime as compared to existing protocols.

An energy-efficient routing algorithm for WSN has been introduced by Khan et al. [63]. The routing approach consists of data transmission, an efficient CH election algorithm, and a cluster formation scheme. Based on the energy analysis for the current routing protocols, a multistage mechanism for data transmission is introduced, and the unnecessary frequency of re-clustering is avoided. As per simulation outcomes, the suggested protocol performed well in terms of the total network lifetime, throughput, and energy efficiency. Unexpected damage to the CHs and forwarder nodes leads to cluster failure and stage insulation, respectively. Azizi et al. introduced an energy-efficient routing strategy for homogeneous and heterogeneous wireless sensor networks [64]. By using a balanced probability threshold, the most capable applicants are chosen to serve as cluster heads. Then, based on the remaining energy and closeness to the base station, the algorithm selects one candidate among the selected cluster heads to serve as a gateway to transmit data to the base station.

A WSN-based energy-efficient weighted-based protocol (EEWBP) for early forest fire detection was developed [65]. The protocol intends to improve coverage and reduce energy consumption to prolong sensor nodes' lives. It utilizes a composite weighted measure that considers variables including trust value, average flying speed, number of neighboring nodes, residual energy, and node degree. EEWBP performs well in terms of energy consumption, packet delivery rate, consistency in the CH, and improvement of first-node death. Zhang et al. proposed an algorithm for CH selection that used the node's weighted election probability, residual energy, and distance from the sink to the sensor node [66]. It has been concluded that heterogeneity variables reflect energy imbalances throughout the network. In addition, this protocol has the longest stability for specific energy and the optimum distance weight compared to other protocols. A two-level heterogeneity awareness routing technique was proposed that divides the network field into two zones based on the initial energy of nodes [67]. The CH selection in this protocol is based on the residual energy and the neighbors' number for each node within the cluster radius. Based on the numerical simulations, the proposed algorithm is energy-efficient and outperforms the other protocols in terms of network lifespan, stability, residual energy, and throughput.

A routing technique for mobile sensor nodes for heterogeneous hierarchical WSNs was developed by Toor and Jain [68]. It selects the node with the highest energy as CH. The algorithm considers hierarchical heterogeneous clustering with three levels of sensor nodes. The network field is divided into sectors, and within each one, a mobile sensor node exists acting as a Mobile Data Collector (MDC) for CH data collection. The evaluation results indicated that the proposed algorithm performed better in terms of throughput, number of cluster heads, dead nodes, stability, and network lifespan.

B. AI-BASED ROUTING PROTOCOLS

A Spider Monkey Optimization algorithm called SMOCH for optimal CH selection was proposed using a greedy selection procedure to choose between newly produced positions and old node positions [69]. In SMOCH, swarms are split up into many groups where each group communicates with the others to improve routing capabilities, and all swarms act simultaneously without a central coordinator. SMOCH is a self-organized, decentralized, and interpretable clustering protocol. An optimization algorithm has been studied to improve the LEACH cluster head election process and network lifetime [70]. This study produced a LEACH-CHIO protocol based on the Coronavirus Herd Immunity Optimizer (CHIO) algorithm. CHIO expects to significantly enhance the LEACH cluster head selection procedure. The simulation outcomes showed that the suggested approach outperformed the standard LEACH routing protocol.

A Thermal Exchange Optimization Inspired by Newton's Cooling Routing Protocol (TEO-MCRP) has been designed as a mobile clustering routing technique for heterogeneous WSNs inspired by Newton's cooling rule and based on Thermal Exchange Optimization (TEO) [71]. The protocol proposes two distinct procedures for CH election and Mobile Sink (MS) route identification, each with separate fitness factors. The data delivery rate in the network was 99.784% due to reduced packet collisions and losses. The mobile sink makes the protocol appropriate for security and surveillance applications rather than indoor monitoring. Benelhouri et al. proposed a protocol that divides the network area into three zones: the direct zone, in which the sensor nodes submit the data directly to the BS; zone G, where a gateway node is used to decrease the transition distance; and zone C1,2, where a CH is used to aggregate the data, which is then submitted to the BS [72]. The protocol used a developed genetic algorithm for optimal CH selection and enhancing WSN coverage.

Singh et al. utilized mobile sinks and direct collection of data for a heterogeneous protocol in a secure and energy-efficient routing algorithm-based Internet of Medical Things (IoMT) for patient and doctor interaction using a genetic algorithm [73]. The study shows that the suggested protocol outperforms the comparative protocols in many aspects of evaluation metrics. However, there is no solution for the unexpected death of a sink node related to environmental conditions.

A routing protocol for forest fire detection (RPLS) has been developed by Moussa et al. [74]. It is based on software-defined network (SDN)-enabled WSNs and reinforcement learning (RL). The proposed protocol incorporates a clustering algorithm to save energy and reduce the cluster radius, depending on energy variables and link quality. The consequence of the SDN controller's intelligent definition of optimal routes is improved network operating lifespan and response time, which take reliability, energy efficiency, and real-time responsiveness into account. The study by Navi et al. introduced the High-Quality Clustering Algorithm (HQCA) for producing high-quality clusters [75]. The HQCA approach employs criteria for assessing cluster quality, which can enhance inter- and intra-cluster distances and minimize the clustering error rate. The optimum CH is elected by fuzzy logic based on several factors, including remaining energy, the lowest and highest energy in each cluster, and the shortest and longest distances among the cluster nodes and the BS location.

Biabani et al. present an evolutionary strategy for clustering and data routing that may control the node's energy consumption while considering disaster area features [76]. The algorithm introduced a model with an improved Particle Swarm Optimization (PSO) and Harmony Search Algorithm (HAS) for CH selection. Furthermore, create a multi-hop routing system based on PSO with improved tree encoding and an enhanced data packet format. Simulated outcomes for disaster scenarios demonstrate that the suggested method was efficient in comparison to state-of-the-art techniques. It is a centralized algorithm; therefore, the sink is responsible for clustering and routing. Consequently, unaware sink damage led to clustering and routing failure. Rani et al. proposed two fault-tolerance approaches for clustering and routing [77]. The algorithm utilized a backup CH selection to ensure data communication in the event of a CH failure. Moreover, an aggregator node is also selected to improve the data routing using an optimized algorithm. The proposed method enhanced throughput and reduced network overhead. However, it is not adequate in fire incidents since the temperature level was not considered a metric when electing the CHs, backup CHs, and aggregator nodes. Samayveer et al. proposed a new CH selection algorithm for the IoT-enabled heterogeneous WSNs for a smart city's distributed architecture [78]. A Hybrid Genetic Algorithm Routing Protocol (HGA-RP) inspired by greedy strategy-based mutation was also achieved to extend the network's functional lifetime and ensure energy conservation. The protocol further executes a new node's deployment strategy.

The previous protocols were unreliable in fire incidents as network segmentation and packet routing failure issues in fire incidents were not addressed. In addition, there is no awareness of the unexpected loss of CH or central nodes. Moreover, for most of the routing algorithms, the BS is located at the center or on the border of the sensing domain, making it extremely sensitive to being destroyed by fire exploding within the network area, resulting in the loss of all monitored data. The performance parameters for the reviewed routing algorithms are discussed in Table 3.

- **Scalability Level (SL)**: A good scalable protocol has a good ability to survive and perform effectively under an expanding workload, where the network maintains performance regardless of the increased size of the network [79].
- **Hop Count (HC)**: Effect on energy consumption of the sensor nodes and CHs. The short-hop approach is less energy-intensive, as sensor nodes use less communication power over shorter distances [80]. Two hop count schemes are organized in clustering algorithms: the single hop, where the data packets within the cluster travel from the sensor node to the CH, and the multi-hop, where the data packets within the cluster travel via a mediator node(s) from the sensor node to the CH or sink node. Moreover, direct communication is achieved when the sensor node transmits the data directly to the sink.
- **Mobility**: In WSNs, the sensor nodes as well as the sink node could be either Mobile (M) or Static (S), depending on the function and application. Accordingly, node mobility is essential in various applications, such as surveillance, object tracking, and wildlife monitoring, but more power is consumed [81]. On the other hand,stationary nodes are employed in indoor monitoring networks, where they are easy to deploy and maintain. However, a network partition occurs if any node fails in static WSNs [79].
- **Network Heterogeneity**: In homogenous (H) protocols, the sensor nodes have identical properties and functionalities, so any sensor node could be a CH. Therefore, in non-homogenous (NH) protocols, the hardware complexity is only observed in the CHs.

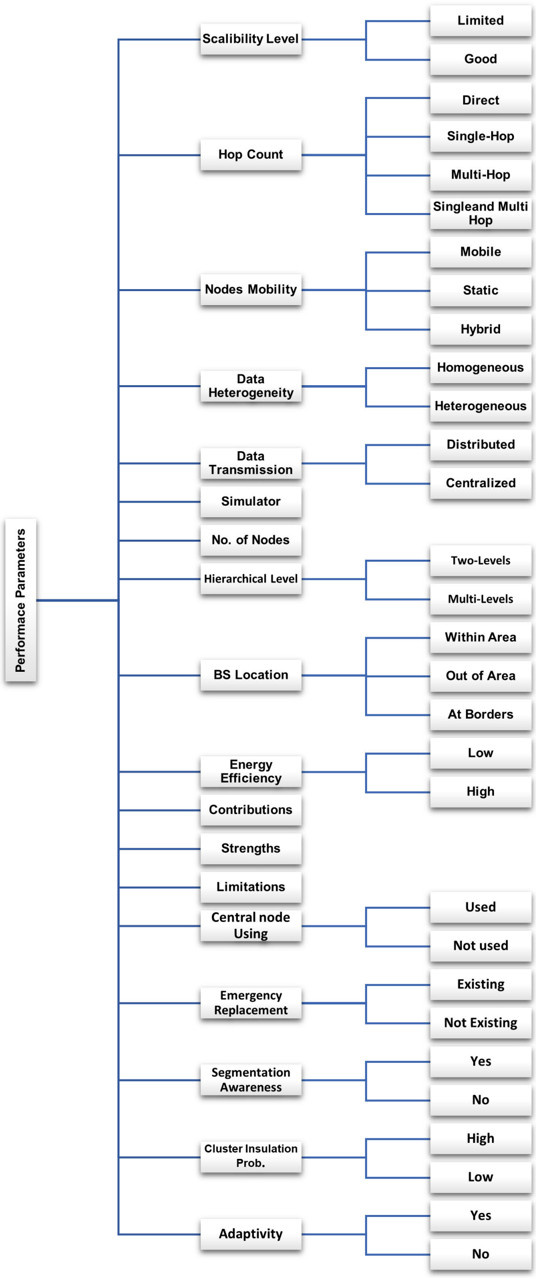

FIGURE 4. Comparative performance parameters of the reviewed routing algorithms.

As compared to homogeneous protocols, heterogeneous protocols are less susceptible to node failure [82].

- **Data Transmission**: It is within the scope of the CH selection procedure. If the algorithm operates in a Distributed (D) mode, then the function of the BS is limited to receiving the transmitted data from CHs. On the other hand, an even distribution of CHs in the whole network is achieved by utilizing the Centralized (C) approach [79]. However, the centralized algorithm consumes more energy at start-up. For WSNs working within a stable environment, centralized architecture could be more reliable, whereas distributed architecture

TABLE 3. General comparative parameters among reviewed routing protocols.

Study	Approach	Description	SL	HC	M/S	H/NH	D/C	Simulator	No. of Nodes	EE/ Network Lifetime	Hie. Level/ In/outdoor
Daanoune *et al.* [51]	ACCRP	Adaptive Coding Clustered Routing Protocol	Good	Multi-hop and single hop	Static	H	D	MATLAB	100	EE: Improved to 75%	Two levels/ N/A
Han *et al.* [52]	HCEH-UC	Adaptive Cluster-Based Routing Protocol for Energy-Harvesting WSN	Good	Multi-hop	Static	NH	D	MATLAB	100	EE: High	Two levels/ Indoor
Sridharan *et al.* [53]	LHRP	Lifetime Enhancement Routing Protocol	Limited	Multi-hop	Static	NH	D	MATLAB	100	EE: High	Multi-levels N/A
Bharany *et al.* [54]	EE-LEACH	Energy-Efficient LEACH	Good	Multi-hop	Mobile	H	D	MATLAB	100	118% increased network lifetime	Two levels/ Outdoor
Ullah *et al.* [55]	OLSR	Optimized Link State Routing	Good	Multi-hop	Mobile	H	D	NS2	10,20 and 30	N/A	Two levels Outdoors/ Indoor
Pedditi *et al.* [56]	EERP	Energy Efficient Routing Protocol	Good	Multi-hop	Static	H	D	Python	100, 200	EE: High	Two levels/ Indoor
Benelhouri *et al.* [57]	IGEAMR	Improved Gateway-Based Energy-Aware Multi-Hop Routing Protocol	Good	Multi-hop and Direct	Static	H	D	N/A	100	218% prolonged network lifetime	Multi-levels Indoors
Zhao *et al.* [58]	SSEEP	State-Switchable Energy- Conserving Routing Protocol	Good	Multi-hop	Static	NH	D	N/A	100	Improve EE	Two levels/ Indoor
Chithaluru *et al.* [59]	ETH-LEACH	Energy Enhanced Threshold Routing Protocol for LEACH	Limited	Multi-hop	Static	H	D	MATLAB	10-100	EE: High Prolonged network lifetime	Multi-levels N/A
Diakhate *et al.* [60]	EERP-DA	Energy-Efficient Routing Protocol-based Dijkstra Algorithm	Good	Multi-hop	Static	H	D	MATLAB	100	Improve EE and network lifetime	Two levels/ N/A
Jibreel *et al.* [61]	HMGEAR	Enhanced Heterogeneous Gateway-based Energy-Aware multi-hop Routing	Good	Multi-Hop and direct	Static	NH	D	MATLAB	100	Improve EE and network lifetime	Multi-levels/ Indoor
Zhang *et al.* [62]	HTC-RDC	Hybrid Tree-Based and Cluster-Based Routing Protocol for Raw Data Collection	Good	Multi-Hop	Static	H	D	Python	100	11.4% increase average network lifetime	Multi-levels indoor and Outdoor
Khan *et al.* [63]	EE-MRP	Energy-Efficient Multi-stage Routing Protocol	Very Good	Direct, Single and Multi-hop	Static	H	D	MATLAB	100	155% increase in network lifetime	Multi-levels/ Indoor
AZIZI *et al.* [64]	EECP	Energy-Efficient Clustering Protocol	Good	Multi-hop	Static	NH and H	D	MATLAB	100	EE: High	Two levels/ N/A
Kaur *et al.* [65]	EEWBP	Energy-Efficient Weighted-Based Protocol	Good	Multi-hop	Static	NH and H	D	MATLAB	100	EE: High	Two levels/ Outdoor
Zhang *et al.* [66]	E-BEENISH	Enhanced Balanced Energy Efficient Network-Integrated Super-Heterogeneous	Good	Single hop	Static	NH	D	MATLAB	100	Improve EE and network lifetime	Two levels/ Indoor
Alom *et al.* [67]	IZ-SEP	Improved Zonal Stable Election Protocol	Good	Direct and Multi-hop	Static	NH	D	MATLAB	100	EE: Improved to 57%, prolonged lifetime to 44%	Two levels/ Indoor
Toor *et al.* [68]	MEACBM	Mobile Energy Aware Cluster-Based Multi-hop	Limited	Multi-hop	Mobile sink	NH	D	MATLAB	100	Prolong network lifetime	Multi-levels/ Indoor
Gui *et al.* [69]	SMOCH	Spider Monkey Optimization Cluster Head	Very Good	Multi-hop	Static	H	D	MATLAB	100	EE: High	Two levels/ N/A

TABLE 3. *(Continued.)* **General comparative parameters among reviewed routing protocols.**

Faris *et al.* [70]	LEACH-CHIO	LEACH- Coronavirus Herd Immunity Optimizer	Limited	Single hop	Static	H	C	MATLAB	100	EE: High	Two levels/ Indoor
Yalçın *et al.* [71]	TEO-MCRP	Thermal Exchange Optimization Inspired by Newton's Cooling Routing Protocol	Good	Multi-hop	Mobile sink	NH	D	MATLAB	500	EE: High	Muli levels/ Indoor
Benelhouri *et al.* [72]	E-GLBR	Evolutionary Gateway-based Load-Balanced Routing	Limited	Direct and Multi hop	Static	NH	D	MATLAB	500	EE: High	Two levels/ N/A
Singh *et al.* [73]	OptiGeA	Optimized Genetic Algorithm	Good	Direct and Multi-hop	Mobile sinks	NH	D	MATLAB	100	66.95% Increased network lifetime	Multi levels/ Indoor
Moussa *et al.* [74]	RPLS	Routing Protocol for Forest Fire Detection	Good	Multi-hop	Static	H	C	Castalia	49	14.06% Improved network lifetime	Multi-levels Outdoor
Navi *et al.* [75]	HQCA-WSN	High-Quality Clustering Algorithm	Good	Multi-hop	Static	NH	D	MATLAB	500	EE: High, improve network lifetime	Two levels / N/A
Biabani *et al.* [76]	ECHSR	Energy-Efficient Cluster Head Selection and Routing	Good	Multi-hop	Static	H	C	MATLAB	100	Improve EE and network lifetime	Multi-levels/ Outdoor
Rani *et al.* [77]	FTOR-Mod PSO	Fault Tolerance- and Optimal Relay Node Modified PSO	Good	Multi-hop	Static	H	D	NS2	100	EE: Improve to 91.43%	Two levels / N/A
Singh *et al.* [78]	HGA-RP	Hybrid Genetic Algorithm Routing Protocol	Good	Multi-hop	Mobile Sink	NH	D	MATLAB	100	31.41% Improved network lifetime	Multi-levels Outdoor

might be stronger for WSNs functioning in a dynamic environment [83].

- **Energy Efficiency (EE) and Network Lifetime**: These metrics describe if the suggested protocol has better energy efficiency and network lifetime when compared to state-of-the-art algorithms.
- **Hierarchical Level (Hie. Level)**: It is divided into two-level clustering and multi-level clustering. In two-level clustering, each CH independently transmits the data to the BS, while in multi-level clustering, each CH transmits the data to other CHs or a central node until it reaches the BS [84].
- **Sensing Area (In/outdoor)**: It is either indoors or outdoors. Indoor networks are used in applications such as healthcare, temperature and humidity monitoring in a greenhouse, and smart house security. While outdoor networks are utilized in applications such as agriculture management and flood monitoring [85].

This section has studied the general description and methodology of the proposed protocols, as well as their contributions, strengths, and limitations. Different performance parameters for the reviewed protocols were assigned in Table 3.

In the next section, a thorough analysis of the most important architectural challenges that the algorithms encounter in fire incidents will be discussed. Fig. 4 illustrates the performance parameters used in the comparisons within this section and the next section.

VII. ANALYSIS OF ARCHITECTURE CHALLENGES IN FIRE INCIDENTS

In the previous section, various kinds of clustered routing protocols have been evaluated based on several performance parameters, such as energy efficiency, network lifetime, hop count, data transmission scheme, and scalability level, as well as their contributions, strengths, and limitations. The comparison demonstrates that the clustering approach is one of the most energy-efficient solutions for routing protocols. Furthermore, multi-hop schemes save energy better than single-hop schemes because they reduce the transmission distance between nodes and BS. In addition, heterogeneous protocols are more suitable for real-world scenarios than homogenous protocols.

The reviewed routing approaches are primarily concerned with energy-efficient routing schemes; however, they need to address the algorithm's adaptability in unexpected events like sudden fires or earthquakes. Moreover, the routing algorithms are based mainly on energy reduction for head node replacement; therefore, there is no emergency replacement procedure for the sudden loss of high-energy head nodes such as gateways, cluster heads, or sink nodes. Thus, unforeseen head node damage causes data routing failure and, accordingly, the loss of monitored data. Many issues could

TABLE 4. The contributions, strengths, and limitations of the reviewed routing protocols.

Study	Approach	Contributions	Strengths	Limitations
Daanoune *et al.* [51]	ACCRP	Abandoned Node (AN) addition; implements Low-Density Parity-Check (LDPC) and Reed Solomon (RS) codes to a routing protocol	Stability; improved network lifetime, energy efficient, and throughput	Numerous computations were needed; latency and packet delivery ratios were not addressed
Han *et al.* [52]	HCEH-UC	Clustering termination criteria were modified adaptively based on node deployment; proposed a mechanism for data transmission adjustment	Balanced energy consumption; control the node number of the energy harvesting mode	Unreliable network when several nodes are in a sleep state; redundancy problem
Sridharan *et al.* [53]	LHRP	Formulation of a hypergraph for p-clustering of nodes. Using the Upper Triangular Matrix (UTM) Lie algebra for efficient routing	Good performance in terms of packets sent to BS, consumed energy, number of alive nodes, and network lifetime	Packet delivery ratio, node failure, throughput, and delay were not addressed
Bharany *et al.* [54]	EE-LEACH	An energy-efficient clustering algorithm for data transmission	Reliability; improved network lifetime; energy efficient	Complexity; BS locations inside the network field are not recommended for disaster areas
Ullah *et al.* [55]	OLSR	Evaluated the performance with varying network densities; use network simulation to assess the firefighters' effectiveness	Better performance in terms of average throughput, average latency, and average packet drop	The network's highly mobile nature and varying network densities can be a challenge
Pedditi *et al.* [56]	EERP	Develop an efficient clustering and routing approach	Reduce the energy consumption and extend the network lifetime	Homogenous networks may not reflect real-world conditions
Benelhouri *et al.* [57]	IGEAMR	Improved the standard Multi-Hop Gateway-Based Energy-Aware Routing (MGEAR) protocol to equalize the load and enhance the lifetime	Enhanced throughput and network lifetime	Based on the network structure, losing of a gateway node results in losing 80% of monitored data
Zhao *et al.* [58]	SSEEP	Only useful information could be submitted in a timely and reliable manner; an optimal number of CHs was adopted	The threshold value controls the data transmission; enhanced network lifetime	If a few nodes are alive, then the network cannot be clustered, and the energy will be exhausted
Chithaluru *et al.* [59]	ETH-LEACH	Developed an approach for the adaptive ranking of CH and forwarder nodes. Address the issue of resource waste in the standard LEACH protocol	Extend the network lifetime, reduce energy consumption, and improve the stability	Not scalable; not suitable for dynamic network topology.
Diakhate *et al.* [60]	EERP-DA	Using Dijkstra's algorithm for the shortest path selection between the CH and the BS	Optimize network lifetime and minimize energy consumption	The impact of various deployment scenarios or network topologies on the effectiveness of the suggested technique was not explored
Jibreel *et al.* [61]	HMGEAR	Design a heterogeneous version of the traditional homogeneous MGEAR protocol	Improved stability period, throughput, residual energy, and network lifespan	Region's insulation in unforeseen burning of head nodes or gateways
Zhang *et al.* [62]	HTC-RDC	Raw data collection without redundant sensor nodes in practical scenarios. Incorporation of hybrid tree-based routing protocol	Prolonged the network lifetime; low computational complexity; energy-adaptive approach	High energy consumption
Khan *et al.* [63]	EE-MRP	A multi-stage data transmission mechanism; efficient CH selection algorithm	Improved network lifetime, throughput, and energy efficiency	Node's homogeneity makes the network insufficient for real-world monitoring; routing failure in unexpected die for the CHs or forwarder node
AZIZI *et al.* [64]	EECP	Add a new data-transmission hierarchical layer to the BS; the best CH candidate will serve as a gateway	Improved energy efficiency, network longevity, and amount of transmitted data	Node homogeneity makes the network insufficient for real-world monitoring
Kaur *et al.* [65]	EEWBP	Integration of weighted metrics to help in node-scheduling processes and cluster-building. A new clustering routing algorithm	Enhanced in first node die and packet delivery rate	Needs an aggregation procedure to discard the processing of the identical packet. Congestion issue
Zhang *et al.* [66]	E-BEENISH	Develop a CH selection algorithm; incorporate a normalized weighting constant to optimize network lifespan	Improved energy efficiency, load balancing, and network lifetime	Algorithm complexity; data transmission latency
Alom *et al.* [67]	IZ-SEP	Improved CH selection algorithm	Enhanced stability period, network lifespan, and throughput	The QoS was not addressed; inefficient node deployment
Toor *et al.* [68]	MEACBM	The protocol selects CHs with a higher energy state among other nodes	Improved throughput, stability, and network lifespan; reduced number of dead nodes	Limited scalability
Gui *et al.* [69]	SMOCH	A new CH selection algorithm based on Spider-Monkey Optimization algorithm	Self-organizing behaviors; multi-path model capability; simple to develop and interpretant	Cannot maintain subgroup sizes fixed during the foraging process

TABLE 4. *(Continued.)* **The contributions, strengths, and limitations of the reviewed routing protocols.**

Faris *et al.* [70]	LEACH-CHIO	An optimization process of CHs selection based on the highest energy	Prolonged network lifetime; increased received packet number; energy consumption reduction	Limited scalability
Yalçın *et al.* [71]	TEO-MCRP	Multi-purpose fitness parameters for clustering; robust CH selection	Improved network lifetime; balanced energy depletion; increased packet delivery rate	High complexity that may affect the energy cost and scalability
Benelhouri *et al.* [72]	E-GLBR	Efficient CH selection algorithm using a developed fitness function for the Genetic Algorithm (GA) optimization approach	Load balancing; QoS enhancement; optimal CH selection	Low throughput; hot spot problem that caused transmitting data losing
Singh *et al.* [73]	OptiGeA	Performed clustering using efficient parameters; heterogeneous node's capacity for patient data collection	Reduce transmission distance between the sink and CHs; minimize hotspot issue	More energy and maintenance are needed for the mobile sinks
Moussa *et al.* [74]	RPLS	Used SDN and RL to improve the performance of the WSNs. An energy-efficient topology to minimizes the control packet used	Enhance energy efficiency, reliability, response time, network lifetime, real-time responsiveness, scalability, and reactivity	Homogenous nodes do not reflect real-world conditions
Navi *et al.* [75]	HQCA-WSN	Developed C-means algorithm for better cluster centers and fuzzy logic for optimal CH selection	Low error rate; high reliability; good scalability	Cost-effective if the initial energy for each node is low
Biabani *et al.* [76]	ECHSR	Energy-efficient clustering and routing, while considering disaster area characteristics	Improved residual energy, live nodes' number, network coverage, and packet delivery ratio	Extensive delays for routing decisions; nodes' position awareness was not considered, which can affect the performance in disaster scenarios
Rani *et al.* [77]	FTOR-Mod PSO	Two-Fault tolerance approaches are used to select optimal CHs, backup CHs, and Aggregator Node (AG) based on Battle Royale Optimization Algorithm (BRO)	Higher throughput; reduced routing overhead and consumed energy; ensured data communication	The sudden loss of the CH, Backup Cluster Head (BKCH), and AG was not addressed; the node's homogeneity makes the network insufficient for real-world scenarios
Singh *et al.* [78]	HGA-RP	Introduced a new weighted fitness function for the hybrid genetic algorithm. Consider an energy-conserving model for a smart city. A new nodes' deployment strategy	Improve the consumed energy and network lifetime. Reliable CH selection method	Faulty node detection and recovery were not addressed

cause network segmentation and data routing failures, such as physical link failures, network congestion, security attacks, earthquakes, or fires. The whole prevention mechanism often varies depending on the reason. For instance, the network must be configured to be sensitive to earthquakes and fires, and to prevent physical link failures, the network should have proper design, deployment, and configuration management, while for security attacks, the network must evolve security measures and achievements. In this study, we will focus only on the major architectural challenges that might cause data routing failures in clustered routing protocols for fire incidents. The following is a summary of the primary architectural challenges of the previously studied algorithms that might lead to network segmentation and data loss during fire incidents:

a) **BS Location:** The BSs are more susceptible to destruction during fire incidents if they are located within or on the border of the network area. This will lead to the loss of all monitored data and a failure to deliver data to the control system. Hence, the algorithms with BS inside the network area are ineffective in harsh environments, particularly indoor fires.

b) **Central Node Using:** It could be a gateway, a forwarder node, or any mediator node. These nodes are frequently employed to extend the network lifetime, improve energy efficiency through multi-hop, and decrease the transmission distance from source to destination. However, the data delivery failure imposed by the unexpected loss of these nodes will segment the network and result in the loss of the collected data that these nodes were supposed to deliver to the BS.

c) **Cluster Insulation:** In most algorithms, the clustering procedure contains two phases: setup and steady-state phases. The clusters are usually created in the setup phase via four standard steps, which are the CH election, CH role declaration, cluster formation, and Time Division Multiple Access (TDMA) schedule generation [86]. When a CH is selected, it transmits an Advertisement (ADV) message to the sensor nodes within its domain, informing the nodes that it is the new CH. Every non-CH node decides to join the optimum CH based on predefined metrics. Then, each CH generates and broadcasts a TDMA schedule to the sensor members. While in the steady-state phase, each cluster member wakes up repeatedly according to the given time slot [87].

The existing routing algorithms do not consider the loss of an active CH during the round time. Thus, if an active CH burns during a fire incident, then the routing algorithm will replace it with an energy-efficient node in the next round while losing all the data acquired from cluster members in the current round. Moreover, if the fire keeps growing, a similar issue will arise in the next round, causing more data loss because the CH replacement does not consider the essential metrics of fire occurrence, such as temperature level and distance from the burned node.

Table 5 describes the major architecture challenges for the reviewed routing protocols in fire incidents. Where the BS location is assigned for each approach and shows whether the protocols employed a central node. In addition, except for the studies [76], [77], none of the reviewed routing schemes show any awareness of the network segmentations caused by topology distortion during fires. However, in the two mentioned studies, the BS is located inside the network field, making the algorithms nonadaptive to fire incidents as well. Moreover, in all algorithms, there is no emergency replacement for burning or dying high-energy CHs or central nodes during fires, as the algorithms are based on energy reduction for CHs or central node replacement. Thus, the cluster insulation probability in fire incidents is "high" for all approaches except the study [76], where cluster insulation is considered; however, the BS location makes the algorithms nonadaptive to fire incidents. As a result, none of the reviewed algorithms are fully adaptive to fire incidents.

Based on the conceptual description of the architecture challenges shown in Fig. 5, 96% of the evaluated algorithms face the issue of cluster insulation in fire incidents. Therefore, it can be considered the most present challenge in the hierarchical protocols on fire occurrence. Furthermore, 50% of the algorithms locate the BS inside or on the border of the sensing field, which makes it vulnerable to damage during fire accidents. Also, 53% of the analyzed approaches employed a central node in network architecture, such as a gateway or forwarder node. If one or more of these challenges are present in the protocol and an unexpected fire breaks out, then the network will be segmented and the data routing process will fail, subsequently losing the collected data and rendering the protocol useless.

To further examine the challenges, consider a 100mx100m network with hierarchical clustering employment, as illustrated in Fig. 6. The normal conditions were considered in (a), where there was no fire explosion, and the BS was located inside the network area. In (b), also under normal conditions, a gateway was employed to improve the network's lifetime, and BS was placed outside the network area. In (a) and (b), there are no issues regarding data transmission because it was considered a normal environment, and the routing algorithm replaced the CHs or gateway nodes based on energy criteria.

The BS location challenge is addressed in (c); if a fire broke out near the BS, all submitted data from the CHs to the BS would be lost. This might be regarded as the worst scenario since it results in the total loss of the data at once since the BS is responsible for data submission to the control system. Furthermore, there is no alternative for the BS in the existing routing algorithms since the BS is a robust node with significant energy support; thus, losing the BS makes the protocol useless.

TABLE 5. **The architecture challenges for the reviewed protocols in fire incidents.**

Study	BS location	Central Nodes Using	Network Segmentation Awareness	Cluster Insulation
[51]	Out of Area	✓	×	High
[52]	Within Area	×	×	High
[53]	Within and Out of Area	✓	×	High
[54]	Within Area	✓	×	High
[55]	Out of Area	✓	×	High
[56]	Out of Area	×	×	High
[57]	Out of Area	✓	×	High
[58]	Out of Area	×	×	High
[59]	Out of Area	✓	×	High
[60]	Within Area	×	×	High
[61]	Out of Area	✓	×	High
[62]	Out of Area	✓	×	High
[63]	Out of Area	✓	×	High
[64]	Out of Area	✓	×	High
[65]	Within Area	×	×	High
[66]	Within Area	×	×	High
[67]	Within Area	×	×	High
[68]	Within Area	✓	×	High
[69]	Out of Area	×	×	High
[70]	At Borders	×	×	High
[71]	Within Area	✓	×	High
[72]	Out of Area	✓	×	High
[73]	Out of Area	×	×	High
[74]	At Border	×	×	High
[75]	Out of Area	×	×	High
[76]	At Borders	×	✓	Low
[77]	Within Area	✓	×	High
[78]	Within Area	✓	×	High

A gateway node employed in (d) is used to transmit all aggregated data from CHs to the BS. Thus, the failure of this node due to fire damage will result in the loss of all transmitted data from CHs. However, depending on the network size, various routing architectures may employ two or more gateway nodes. For instance, 50% of the transmitted data will be dropped if the network uses two gateway nodes, and one of them is lost in a fire incident. Therefore, if gateway nodes are utilized, the probability of data loss in fire incidents will vary based on network architecture and the number of employed gateways.

In (e), when one of the clusters caught fire and caused damage to the CH, 25% of the data would be lost during the current round before the algorithm replaced it with an efficient one in the next round. Moreover, the new CH will be selected mostly based on energy and some other metrics, disregarding the significant criteria in fire incidents such as distance from lost CH and temperature levels. These criteria should be considered to prevent the selection of CH that is also close to a fire source and may be destroyed

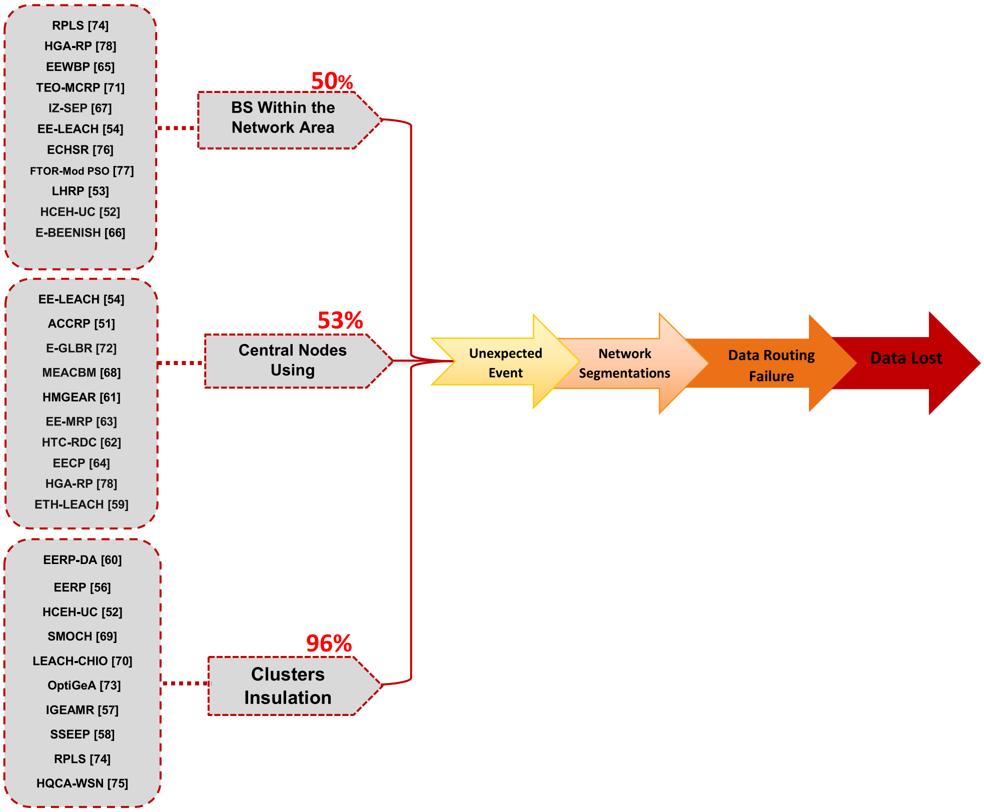

FIGURE 5. **Conceptual description of the protocols' architecture challenges in fire incidents.**

too. Therefore, increased fire progress might cause cluster insulation for further rounds. Additionally, if the fire spreads to another cluster, the probability of data loss will grow. Thus, 50% of the monitored data would be lost if two of the clusters were damaged, and so on. The data loss probability for the assumed four-cluster network architecture based on various scenarios is addressed in Fig. 7.

The crossover among the evaluated architecture challenges is described in Fig. 8. Circle A refers to the BS-location challenge, Circle B refers to the cluster insulation challenge, and Circle C refers to the central node challenge. Based on the figure, we can conclude the following:

- Cluster insulation is the most significant issue that all hierarchical protocols might encounter in fire incidents.
- Some reviewed protocols have a central node as part of their architecture. If it does exist, it often occurs in conjunction with the cluster insulation challenge rather than by itself, because in the hierarchical protocols, a central node oversees delivering the CHs' aggregated data to the BS. As a result, a protocol with a central node utilization challenge cannot be seen without a cluster insulation challenge.
- From the above two facts, no protocol could combine the challenges of the BS location and central node alone without incorporating cluster insulation.

Finally, the research gaps can be highlighted as follows:

- Current routing protocols frequently lack reliable mechanisms to prevent data loss during fire incidents. The significant possibility of node failure or damage may lead to substantial data loss, which is crucial in emergencies. Advanced data-rerouting methods, such as deep learning techniques, are required. In addition, research is vital to developing protocols that preserve data integrity and reliability in unpredictable, changing environments.
- Fire incidents may cause isolated network segments and communication deformations. There is a lack of protocols capable of dynamically reconfiguring the network to preserve the connection. Current solutions frequently fall short of seamlessly restoring the connection in segmented networks. Developing approaches to bridge unconnected network segments without substantial delays is a significant research gap.
- Existing fault-tolerance routing protocols may not be flexible enough to manage various routing failures during fire conditions. Fault-tolerant routing algorithms must be developed to keep functioning regardless of the number of nodes or connection failures.
- Fire incidents frequently result in network nodes being destroyed or damaged, and energy-efficient protocols that can function with restricted power sources are necessary. Current studies lack substantial solutions that target energy efficiency under such conditions.
- Network performance can be significantly impacted by the loss of head nodes, such as cluster heads, forwarder nodes, gateway nodes, and base stations. These nodes

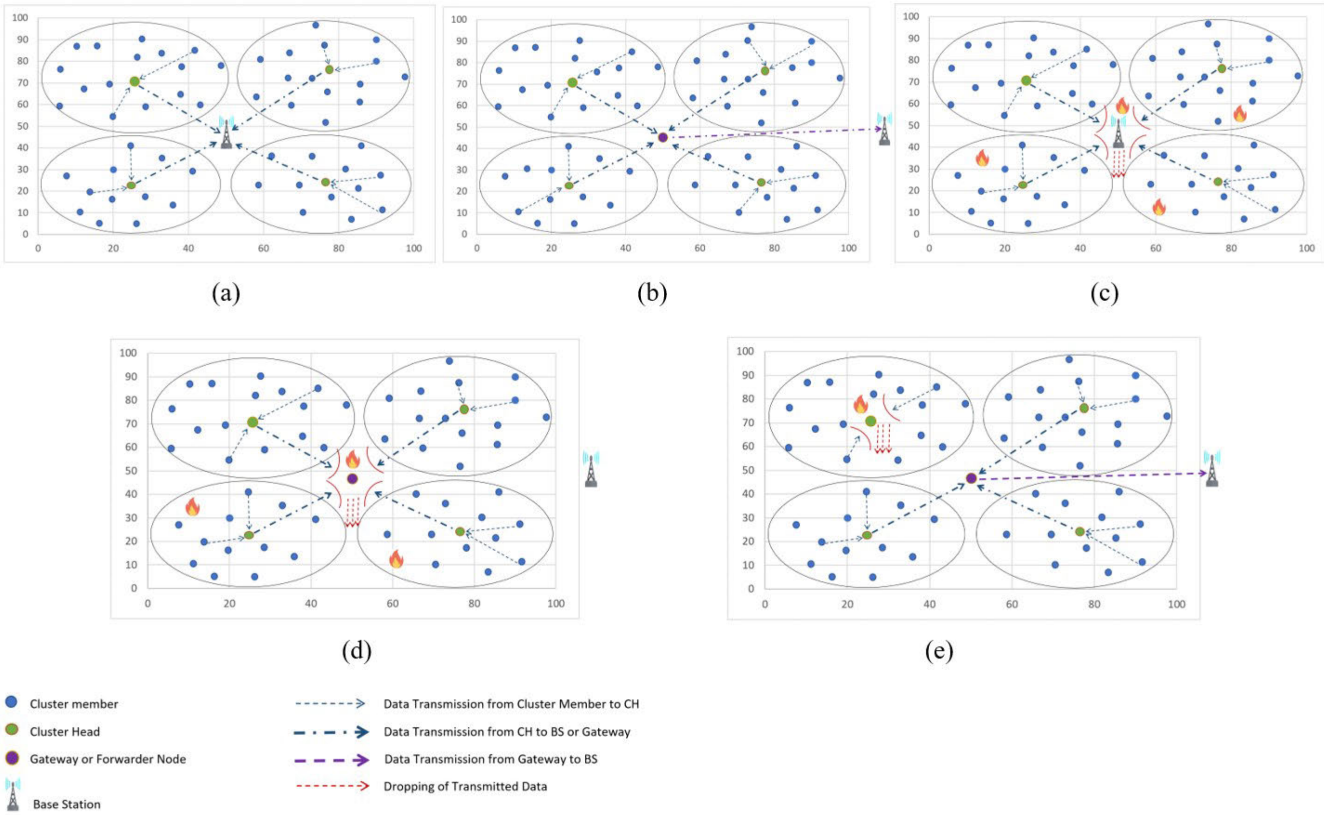

FIGURE 6. Graphical Description for the Architecture Challenges in Fire Incidents for (100 m x 100 m) WSN: (a) In normal conditions and the BS within the network area (b) In normal conditions and the BS outside the network area and gateway node used (c) In a fire incident and the BS within the network area (d) In a fire incident and the BS outside the network area and the gateway has been lost because of fire (e) In a fire incident and the BS outside the network area with gateway used and one of the CHs has been harmed because of fire.

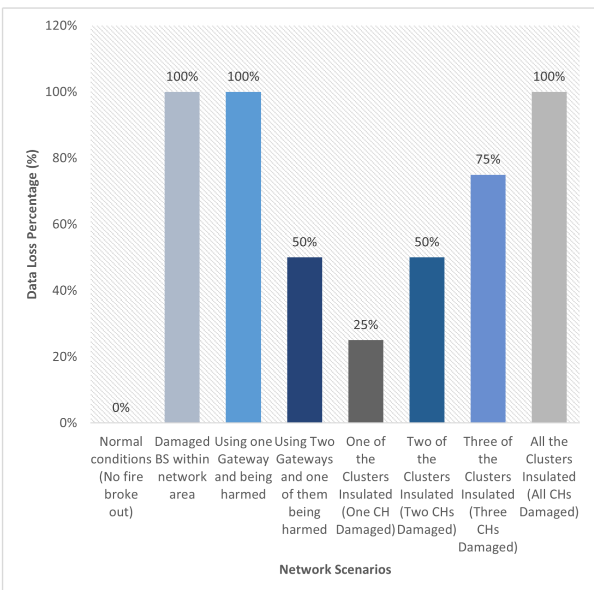

FIGURE 7. Data loss probability on various scenarios for the assumed network architecture.

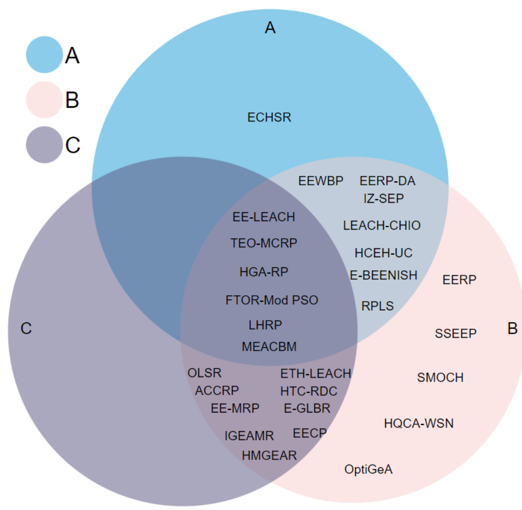

FIGURE 8. The crossover among the architecture challenges in the reviewed protocols: (A) BS-Location Challenge (B) Cluster Insulation Challenge (C) Central Node Using Challenge.

frequently operate as essential hubs for communication. It is crucial to have a robust backbone network that can balance the load, make emergency replacements, and keep the network functioning even if one or more of the main nodes fail.

- Lack of detailed evaluation frameworks to evaluate the applicability of distinct protocols under fire scenarios. The development of standardized criteria and evaluation metrics may help in optimizing protocols for such applications. These metrics include the packet loss ratio and the packet delivery ratio.

- The network topology may change significantly because of fire occurrences. Routing protocols must be able to quickly adapt to these variations to maintain dependable communication despite the changing environment.
- Prioritizing specific data (such as evacuation routes and crucial notifications) is necessary in emergency scenarios. Current protocols frequently lack the necessary QoS guarantees and procedures to prioritize such data.
- Multiple systems are frequently involved in effective fire incident management, such as fire detection systems, communication networks, and emergency response systems. Protocols that may function seamlessly with these many systems are required. Hence, incorporating results from testbeds or hardware experiments provides evidence of the protocols' reliability and efficacy in practical settings, enhancing the theoretical insights explored.

VIII. RECOMMENDED FUTURE DIRECTION

As a result, future research should focus on the design and implementation of application-specific routing algorithms, and the protocol should be adaptive to sudden environmental conditions that cause network topology destruction. The following recommendations are provided in this survey to address the challenges mentioned in the previous section on indoor fire incidents:

a) **BS Relocation**
Within a network, base stations play a crucial role as communication centers, enabling the transfer of data and emergency communication services. Deploying them outside of the network area ensures that they remain functional if a fire event affects the network's infrastructure. By enabling individuals to contact emergency services, organize evacuations, and obtain essential data during emergencies, this contributes to the continuity of service. Setting the BS outside the network area provides redundancy and backup capabilities, offering seamless rerouting of traffic and the establishment of alternative communication paths if the network is disrupted by fire events. This redundancy optimizes the robustness and reliability of the network, decreasing the potential for communication failures during emergencies. As a result, in the hierarchical indoor routing protocols, the BS should be configured outside the network area to be protected from the risk of fire breakout since it controls data delivery from the clusters to the control system. This is the main concern in network architecture to prevent data loss in fire incidents. Some protocols place the BS on the network border, which is likewise unsafe and does not guarantee that the BS would not be harmed by a nearby fire. Therefore, it is ideal for BS to be located outside of the network area in a way that certainly separates it from the fires that occur.

b) **Temperature Sensing by Sensor Node**
In WSNs, the position of each sensor is known, which informs the BS about the range of the sensor and ensures continuous communication with smooth transitions between sensors. Furthermore, all sensors are within the range of wireless communications when connected [88], [89]. This study suggests that sensor nodes within indoor detection networks should have built-in temperature sensing to evaluate the danger level based on temperature variation. This is extremely valuable in fire detection and in controlling both alarm and evacuation procedures in fire incidents. When all sensor nodes within indoor networks have built-in temperature sensing, it may lead to extra energy consumption for sensing and redundant data collection. However, this increase in energy and data is required compared to the frequent advantage of preventing deaths and property damage by ensuring fire data delivery at indoor fire incidents.
For instance, it is undoubtedly improper to neglect to address the level of danger involved in hospital fires, where there may be patients in the operating theater or their cases make it difficult to evacuate quickly. Furthermore, the proposed fault tolerance algorithms for faulty node detection and recovery do not consider temperature levels as a parameter for faulty node replacement, which is critical if nodes have faults due to broken-out fires. Accordingly, it is essential to incorporate temperature sensing within the sensor node so that the algorithm will take the temperature level into account for the burned node's replacement.

c) **Avoid Cluster Insulation and Central Nodes Lost**
The clustering strategy has been extensively utilized to improve routing algorithms since it is seen as an efficient and appropriate approach to delivering data seamlessly. However, CH selection is regarded as a complex procedure since it needs to satisfy certain criteria for efficient performance [90]. The sensor nodes could fail for various reasons, including hardware component failure, battery exhaustion, transmission link issues, instability, and environmental effects. A lot of CH selection approaches focus only on the selection of energy-efficient CHs without considering the unexpected loss of high-energy CHs, which would also result in data routing failure.
The same goes for when the gateway, forwarder, or any central node suddenly fails in fire incidents. Therefore, an intelligent replacement approach for the dead CHs, or central nodes, should be utilized. If these nodes are destroyed, another node with a comparable level of accuracy will take up the responsibilities based on predefined criteria to maintain network functionality.

In the next few sections, we will review and evaluate CH selection techniques, including traditional and intelligent strategies. Moreover, we are discussing whether these techniques are appropriate to employ in the case of central node loss in fire incidents, cluster insulation, and the abrupt death of the CHs. Further, a discussion of the fault tolerance strategies used in routing algorithms is included to demonstrate how effectively they perform in terms of faulty node detection and recovery during a fire.

IX. CH SELECTION METHODS BASED ON THE USED TECHNIQUE

This survey developed a taxonomy of relevant CH selection methods and categorized the different clustering approaches according to the techniques used for the period 2002–2023. It is difficult to review a complete list of all the clustering approaches for the period due to the variety of information, the intersection of related research areas, and the advancement in recent computer technology. Therefore, the commonly employed clustering algorithms with high practical utility and well-studied methodologies are chosen. One or multiple regular algorithm(s) for each category is/are addressed to give readers a systematic and accessible view of the crucial method analysis. The CH selection approaches based on the techniques utilized are categorized as follows in Fig. 9. The oldest are traditional clustering protocols, while the newer ones use hybrid clustering.

1) TRADITIONAL CLUSTERING APPROACHES

In this approach, the clustering operations are performed without using distinctive schemes or optimization techniques. Instead, it is considered the classic method for cluster formation, CH election, and data communication. Traditional clustering is generally based on the probability of CH selection.

Improved LEACH for microsensor networks is used with application-specific data aggregation and media access to introduce reliable performance in terms of system lifespan, delay, and application-perceived quality [91]. In the proposed protocol, each node must decide to become a CH at round r with a probability equal to:

$$P_i(t) = \begin{cases} \dfrac{k}{N-k \times \left(r \mod \frac{N}{k}\right)} & ; C_i(t) = 1 \\ 0 & ; C_i(t) = 0 \end{cases} \tag{1}$$

where i is the node, N is the total number of nodes, k is the expected number of CHs, and $C_i(t)$ is the indicator function. The Energy Dissipation Forecast and Clustering Management (EDFCM) protocol introduced a stable selection and reliable transmission algorithm using a mathematical model through forecasting energy dissipation and clustering management with two levels of hierarchy [92]. It was developed to obtain the optimum number of CHs. However, it does not discuss the network segmentations caused by cluster insulation in the occurrence of sudden events. The weighted probability $P_i(r+1)$ for CH selection is as follows:

$$P_i(r+1) = \begin{cases} \dfrac{p}{(1+\alpha \cdot m)} \left(\dfrac{E_i(r) - E_{PR\_TO}(r)}{\bar{E}(r+1)}\right) \\ \text{If node } i \text{ is type 0\_node} \\ \dfrac{p}{(1+\alpha \cdot m)} \times (1+\alpha) \left(\dfrac{E_i(r) - E_{PR\_T1}(r)}{\bar{E}(r+1)}\right) \\ \text{If node } i \text{ is type 1\_node} \end{cases} \tag{2}$$

where p is the node probability to be selected as a CH, $E\ i(r)$ is the residual energy for the node i in the round r. $E_{PR\_T0}(r)$ and $E_{PR\_T1}(r)$ are the average energy consumption for the two types of CHs in the round r, $\bar{E}(r+1)$ the node's average energy in the round $r+1$, and α, m are the network parameters.

A cluster-based routing protocol called Improved-LEACH (I-LEACH) elects CH nodes based on the geographical position of the sensor node, residual energy, and the number of neighboring nodes [93]. It reduces energy consumption and increases the network's lifetime. The following threshold is used to determine the CH:

$$T(n) = \begin{cases} \dfrac{p}{\left(1-p\left(r \mod \left(\frac{1}{p}\right)\right)\right)} \times \dfrac{E_{cur}}{E_{avg}} \times \dfrac{Nbr_n}{Nbr_{avg}} \\ \times \dfrac{dtoBS_{avg}}{dtoBS_n} \qquad S \in G \\ 0 \qquad \text{otherwise} \end{cases} \tag{3}$$

where G is the set of sensor nodes, E_{cur} represents the power of the current sensor node, E_{avg} denotes the network's average energy for the current round, Nbr_n signifies the number of neighbors for node n, Nbr_{avg} stands for the average number of neighboring nodes, $\text{dtoBS}_{\text{avg}}$ indicates the average distance between sensor nodes to the base station (BS), and dtoBS_n represents the distance from sensor nodes to the BS. Based on the LEACH protocol, a multi-level hierarchical scheme that improves energy efficiency and maximizes network lifespan was introduced with two, three, and four-level [94]. Like LEACH, it is a classic routing algorithm that focuses only on improving energy efficiency with an inefficient CH selection method. A clustered protocol based on a node queuing model to identify network congestion called Priority-Based Application-Specific Congestion Control Clustering Protocol (PASCCC) was proposed by Jan et al. [95]. It used the setup and steady-state phases to perform the clustering. The CH is chosen at random based on the methodology of the LEACH protocol. It makes use of nodes' mobility to control network coverage and connection. In PASCCC, a uniform CH distribution approach was utilized. However, nodes' energy is not considered in the CH selection process. Multi-level route-aware Clustering (MLRC), on the other hand, is a distributed, energy-efficient, and multi-level route-aware protocol [96]. It creates a tree among sensor nodes by employing a route-conscious method that allows nodes to

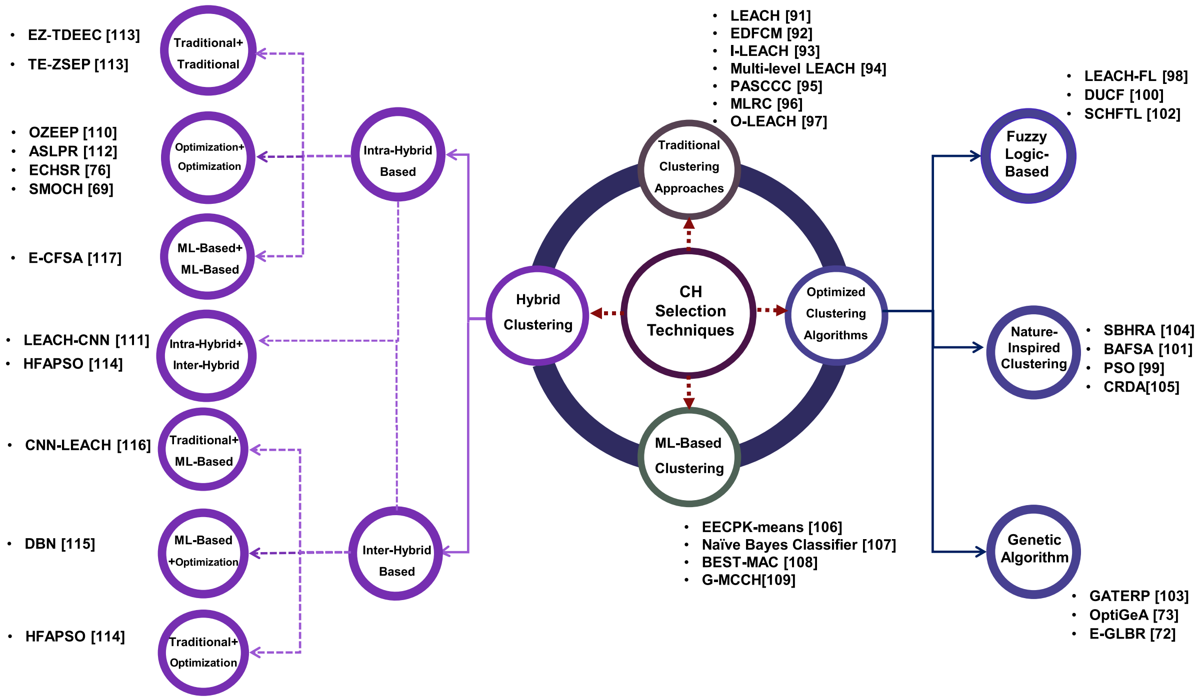

FIGURE 9. Taxonomy of CHs selection techniques.

obtain the required information regarding potential routes to the destination. Any node with a greater energy level than the threshold value will become a candidate to be a CH, and the fitness function will be computed by considering the energy and distance to the BS. The node with the greatest value would be the CH, as follows:

$$CHS_i = a \times Er_i + b \times \frac{1}{dtoBS_i} \tag{4}$$

where E_{r_i} denotes the residual energy of node S_i, and dtoBS_i represents the distance of node S_i to the base station (BS), while a and b are real values.

Siwen et al [97] provided an energy allocation and CH selection method for the Optimized LEACH (O-LEACH) protocol. A new energy threshold is established, and the nodes with lower energy than the threshold are not allowed to compete for CHs. The simulation's results show optimization in the node death time, which extends the LEACH protocol's network lifetime. The energy threshold E is computed by the following equation, where n is a variable with the original value equal to 1 and E_{init} is the initial energy:

$$E = 0.8^n \times E_{init} \tag{5}$$

2) OPTIMIZED CLUSTERING ALGORITHMS

In this survey, optimized clustering is classified into three types: fuzzy logic-based, nature-inspired-based, and genetic algorithm-based. Fuzzy logic is employed in clustering protocols to select CHs and other cluster assignments, improve the protocol's performance, and minimize the challenges caused by the clustering process. Nature-inspired algorithms were also employed in routing protocols. The natural features of continuous Swarm Intelligence (SI) algorithms and bio-inspired algorithms were used productively to solve a given issue. Nature-inspired algorithms are usually used to address challenges such as data aggregation, optimum deployment, clustering, and node localization. Many swarm optimization algorithms have been included in routing algorithms, such as Particle Swarm Optimization, Ant Colony Optimization, Bacteria Foraging Optimization, Artificial Bee Colony, Spider Optimization Algorithm, Monkey Optimization Algorithm, Wolf Optimization Algorithm, Fish Optimization Algorithm, Firefly Optimization Algorithm, and Honeybee Mating Algorithm.

Furthermore, the Genetic Algorithm (GA) is an adaptive approach used to find a random-optimal solution for a specific issue with a substantial number of potential solutions. Genetic algorithms have been extensively employed in various applications, such as clustering, classification, and feature selection. Moreover, the GA is usually applied to routing problems that require multi-objective optimization, which is hard to determine.

Fuzzy logic was used to improve standard LEACH in terms of security and minimize the amount of energy consumed [98]. In LEACH-FL, the sensing area was divided into several equilateral hexagon clusters, and each of them had a cell consisting of six equilateral triangles. Both cells and clusters have an equal number of nodes. Each cell selects a head, and then the CH is chosen from the six cell heads. The CHs probability is given by:

$$\mathrm{Pi}(t) = \begin{cases} \frac{p}{\left(1-p\left(r \bmod \left(\frac{1}{p}\right)\right)\right)} & i \in G \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

where p represents the predicted percentage of the Cluster Head (CH) nodes and r denotes the current round number. Additionally, G signifies the collection of nodes that were not selected as cluster heads in the previous $\frac{1}{p}$ rounds.

A Particle Swarm Optimization scheme (PSO) was used to produce Linear and Nonlinear Programming (LP/NLP) formulas [99]. The routing algorithm has been developed with an effective particle encoding approach and a multi-objective fitness function. Through load balancing, the clustering algorithm takes the nodes' energy conservation into account. To balance the load on the CHs or gateways, the BS executes the clustering algorithm so that the information from the routing solution is utilized for cluster formation. In PSO, the fitness function is inversely proportional to the average distance (AvegDist), and k is the proportionality constant:

$$\text{Fitness} = \frac{k}{\text{AvegDist}} \tag{7}$$

The Distributed Load Balancing-Unequal Clustering Using Fuzzy (DUCF) protocol also used a fuzzy approach to select CHs [100]. DUCF produces unequal clusters to balance the CHs' energy consumption. It utilizes the node degree, distance from the BS, and residual energy as inputs for the CH selection. The output fuzzy parameters in DUCF are chance and size. The protocol uses the maximum limit size of several member nodes for the CH concerning the input fuzzy parameters. Another approach for optimal CH selection is the Breeding Artificial Fish Swarm Algorithm (BAFSA) [101]. The fitness function applied to BAFSA is based on energy and end-to-end delay. The proposed algorithm has fast convergence, good fault tolerance, and valuable local search ability. In addition, it performs effectively in terms of reducing packet loss and improving the network's lifetime. The probability P_i of the fitness function f_i is computed as follows, where i is the fish and N is the total number of fish:

$$P_i = \frac{f_i}{\sum_{J=1}^{N} f_i} \tag{8}$$

To reduce energy consumption and data overhead, the Super Cluster Head Election Using Fuzzy Logic in Three Levels (SCHFTL) protocol introduced three levels of CH selection, where there are cluster heads and supercluster heads [102]. The supercluster head is selected through fuzzy logic. Only the supercluster head is allowed to send data to the BS.

A multi-hop approach using GA was proposed to enhance load balancing and reduce the energy consumption of the distant CHs [103]. The GA-Based Threshold-Sensitive Energy-Efficient Routing Protocol (GATERP) protocol uses GA to select the appropriate CHs and relay nodes. Moreover, the GATERP is suitable for the incident-based application since it replaces the CH that is distant from the BS with a near node. However, it did not pay attention to the dying high-energy CH that was harmed in fire incidents and has a lower preset distance threshold than BS. The routing fitness function between CH_i and CH_j could be specified as follows:

$$\text{f}_{\text{obj\_routing}} = W_R \cdot f_{\text{RE}} + (1 - W_R) \cdot f_D \tag{9}$$

where f_{RE} is the residual energy factor, f_D is the relative distance factor, and $(1 - W_R)$ and W_R are the routing weights associated with f_D and f_{RE}, respectively. The SI algorithm is used in Section-Based Hybrid Routing Protocol with an Artificial Bee Colony (SBHRA) based on the Artificial Bee Colony algorithm (ABC) [104]. SBHRA divides the network into sections with three nodes named, type-1, type-2, and type-3 for a heterogeneous environment. CH selection is performed on type-2 and type-3 regions based on the residual energy. The fitness function for SBHRA is as follows:

$$f^{\text{tpow}} \, \alpha \, \frac{1}{E_H} \quad \Longrightarrow \quad f^{\text{tpow}} = \frac{K}{E_H} \tag{10}$$

where f^{tpow} is the fitness function, E_H is the dissipated energy for the heterogeneous network, and K is the proportionality constant. A cluster-based, reliable data aggregation approach was presented for energy-efficient data transfer and collection [105]. The approach uses an Improved Sunflower Optimization (ISFO) algorithm for CH selection and a deep neural network to compute the routes between the IoT sensors. When compared to the current routing protocols, the suggested method performs better in terms of data transfer rates, throughput, overhead, network lifetime, aggregation latency, and energy usage.

3) MACHINE LEARNING BASED CLUSTERING

Machine Learning (ML) is a division of AI that was introduced in the 1950s. Over time, it developed and advanced to handle many issues in the fields of medicine, computers, and engineering, such as optimization, regression, reinforcement, clustering, and classification. Recent research demonstrates that ML was able to address numerous problems in WSNs. Employing ML in WSNs not only enhances system efficiency but also simplifies complex operations like manual data access, reprogramming, and information extraction from massive amounts of data. Therefore, ML approaches are quite valuable for acquiring enormous amounts of data and extracting relevant information. Many ML techniques have been applied to routing algorithms, such as Deep Learning, Artificial Nurul Networks (ANN), K-means, Fuzzy c-means, Convolution Nurul Network (CNN), Long Short-Term Model (LSTM), Bayesian algorithm, K-Nearest Neighbor algorithm (K-NN), Naïve Bayes Classifier, Support Vector Machine (SVM), and Principal Component Analysis (PCA).

An Energy-Efficient Clustering algorithm based on K-means called EECPK-means has been introduced for WSN [106]. The midpoint algorithm is inserted to enhance the initial centroid selection process. To balance the load on CHs and extend the network lifetime, the suggested method provides balanced clusters. In addition to Euclidean distance, which is a parameter employed in the fundamental K-means method, residual energy is also considered for sufficient CH selection. In EECPK-means, the optimal cluster number K_{opt} could be obtained as follows:

$$K_{opt} = \frac{\sqrt{N}}{\sqrt{2\pi}} \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}} \frac{M}{d_{BS}^2}} \tag{11}$$

Here, d_{BS} is the distance between CH and BS, ε_{fs} is the free-space model parameter, and ε_{mp} is the multipath model parameter. An optimal CH selection algorithm based on a Naïve Bayes classifier was developed [107]. The protocol depends on residual energy and the sum of the Euclidean Distance of member nodes to cluster heads to elect the optimal CH. It is a flexible and effective approach; however, this protocol maintains the classic clustering scheme of the LEACH protocol.

Two algorithms for optimal CH selection and data transmission have been implemented to prolong the network lifetime and throughput [108]. The cluster head election algorithm selects a CH randomly. The backpropagation algorithm is used to determine the shortest paths between CH and the BS as well as between the source and destination. This increases throughput while also saving energy used for transmission and reception. A grid-based CH selection with a Multi-Channel Clustering Hierarchy (G-MCCH) was combined to improve the WSN performance in terms of workload allocation and communication efficiency [109]. The proposed algorithm is divided into grid cells, which then choose CHs from among the nodes in each grid. The results demonstrate that G-MCCH performs better than MCCH in terms of packet loss, throughput, latency, and distance range. The CH was selected only within the area defined by *P_min* and *P_max* based on the following formulas:

$$\begin{aligned} P_{\min(k)} \left|x(i,j) \leq CH_{(K,X)} \leq P_{\max(k)}\right| x(i,j) \\ P_{\min(k)} \left|y(i,j) \leq CH_{(K,y)} \leq P_{\max(k)}\right| y(i,j) \end{aligned} \tag{12}$$

where $P_{\min}(k)$ and $P_{\max}(k)$ are the minimum and maximum grid position points and act as boundaries for the random selection of CH, x is the x-coordinate of the grid cell, y is the y-coordinate of the grid cell, and K is the number of grid cells.

4) HYBRID CLUSTERING

Hybrid clustering combines two or more CH selection techniques to address a particular issue or improve network performance. In this survey, hybrid clustering is divided into two categories: intra-hybrid clustering and inter-hybrid clustering. Intra-hybrid clustering combines two or more clustering methods of the same type, such as two or more optimized methods or two or more ML-based methods. The inter-clustering approach, on the other hand, combines two or more clustering methods of different types, such as optimization techniques with ML-based techniques.

Genetic-Fuzzy or Neuro-Fuzzy was also hybridized to optimize both clustering and CH selection [110]. The two-step clustering operation of the proposed algorithm utilized a fuzzy inference system for the first step to elect optimal nodes that could be CHs. A genetic algorithm was used in the second step to make a final selection of CHs from the nominated candidates introduced by the fuzzy system such that the optimum solution produced is a uniformly distributed balanced cluster, set which enhanced network lifetime. The fitness function for the hybrid proposed algorithm is:

$$\text{fitscore } = \left(ME + CH_{\text{Frac}} + CH_{\text{Speed}}\right) \tag{13}$$

where ME is the Mean communication Energy, CH_Frac is the Cluster Head fraction, and CH_Speed is the Cluster Head speed. The neural network is combined with clustering routing algorithms and data fusion, relying on the network model of the neural network in the context of investigating data fusion and clustering routing protocols [111]. Based on the competition network concept, an enhanced LEACH protocol called CNN-LEACH is presented. The proposed protocol balanced the network load and prolonged the network's lifetime. The fitness function $f(x)$ is shown in the below formula, where p is the sample number, y_p is the actual output, and t_p is the sample output value:

$$f(x) = \frac{1}{1 + \frac{1}{2n}\sum_{p=1}^{n}\left(y_p - t_p\right)} \tag{14}$$

The Application Specific Low Power Routing Protocol (ASLPR) was proposed to prolong the lifetime of the WSN based on the application using LEACH architecture design with an extension to energy forecasting [112]. In this protocol, the genetic algorithm and Simulated Annealing (SA) were combined to set the parameters affecting the threshold determination of CHs selection. A clustering-based application-specific algorithm is produced; it considers some concepts from the sensor nodes for CH selection, such as the distance from the BS, distance from other CHs, residual energy, and the number of previously CH nodes. The adaptive threshold $T_{\text{alprp}}(n)$ for node n in ASLPR is calculated as follows:

$$T_{\text{alprp}}(n) = \begin{cases} a_1T_1(n) + a_2T_2(n) + \\ \quad a_3T_3(n) + a_4T_4(n), & \text{if } E(n) \geq t_1 \times \frac{1}{N}\sum_{i=1}^{N} E(i), \\ 0, & \text{if } E(n) < t_1 \times \frac{1}{N}\sum_{i=1}^{N} E(i). \end{cases} \tag{15}$$

where a_1, a_2, a_3, and a_4 are the four weighting constant metrics provided to adjust the relative influence of the sub-threshold terms for the multi-threshold $T_{\text{alprp}}(n)$. Two hybrid protocols, Zonal Threshold-DEEC and Enhanced Zonal-SEP, were proposed based on the traditional Stable Election Protocol (SEP) and Distributed Energy-Efficient Clustering (DEEC) protocols [113]. The proposed protocols combined the concept of dividing the network area into zones with the new threshold formulation for optimal CH selection. A hybrid of the Firefly Algorithm and Particle Swarm Optimization (HFAPSO) has been proposed in a routing algorithm [114]. The HFAPSO protocol introduced optimal CHs selection that increased the longevity of the network. The fitness function is determined using the residual energy of nodes and the distance between the nodes and CH. Compared to the Firefly method and the traditional LEACH algorithm, the HFAPSO algorithm increased network lifespan and decreased energy usage. The fitness function F is calculated as:

$$F = f1 \times \alpha + f2 \times (1 - \alpha) \tag{16}$$

$$f1 = \sum_{i=1}^{M} E(n_i) / \sum_{j=1}^{N} E(CH_j) \tag{17}$$

$$f2 = \max \left\{ \sum_{i \in j} d(n_i, CH_j) / |\text{ Cluster}_j | \right\} \tag{18}$$

where, f_1 is the energy efficiency metric, f_2 is the distance metric, α is the randomized parameter, M is the set of sensor nodes, N is the set of CHs, $\sum_{i=1}^{M} E(n_i)$ is the sum of energy levels for nodes, $\sum_{j=1}^{N} E(\text{CH}_j)$ is the sum of energy levels for CHs, $\sum_{i \in j} d(n_i, \text{CH}_j)$ is the sum of distances between node n_i and cluster head CH_j, and $|\text{Cluster}_j|$ is the number of nodes in the cluster j.

A deep belief network (DBN)-based routing protocol has been developed to use less energy and improve data transfer along the selected route [115]. As a result, the Packet Delivery Ratio (PDR) gets enhanced. In this framework, a Reinforcement Learning (RL) algorithm is used to organize the nodes into clusters at first and distribute rewards to the cluster members. Then, the Mantaray Foraging Optimization (MRFO) algorithm is used to choose the CH required for effective data transfer. The multi-objective requirements are satisfied by one node, and that node is chosen to be the CH. Using an effective deep-learning method, the data is submitted to the sink node via the selected CH.

Deep learning was also used with the LEACH protocol to enhance network performance [116]. This protocol divides the network into many clusters, each with its own CH, to improve energy efficiency by decreasing the transmission distance. The CH selection was done by CNN based on the network energy levels of the nodes. After each round, the energy of each node is evaluated, and the node with the highest energy is selected as CH.

Another hybrid model for Energy-Efficient Cluster Formation and CH selection (E-CFSA) based on CNN and Modified K-Mean clustering (MKM) was developed for mobile edge computing [117]. The study employed CNN to identify the most effective partitioning for a specific task, the optimum transferring mechanism, and the optimum CHs. Each cluster in the MKM technique has more than one CH to lead. Additionally, it minimizes the number of re-clustering cycles, thus reducing the energy use and delay associated with the re-clustering operation. Table 6 describes the properties of the CH selection methods discussed for the previous routing protocols.

The hybrid strategy integrating two techniques looks like the most efficient for optimal CH selection since it combines the strengths of the two techniques. However, the computational complexity as well as network and communication overhead are a big concern.

Sudden network segmentation awareness in unanticipated events was not incorporated into any of the prior CH selection methods shown in Table 6. Furthermore, the urgent replacement of the damaged energy-efficient CHs was not considered. Consequently, it is recommended that routing protocol developers use an intelligent CH selection technique involving network segmentation awareness and emergency replacement for the CH or any central node to ensure aggregated data delivery to the sink node, which is very substantial for WSN and particularly for fire-detection networks. Table 7 summarizes the comparison between the classification of CH selection methods produced in previous surveys from 2018 to 2023 and their recommendations with this survey's suggestions. Further, the classification comparison with the comparative CH selection surveys is illustrated in Fig. 10.

X. FAULT TOLERANCE ROUTING ALGORITHMS (FTRAS)

The sensor nodes in WSN are prone to failure since they have a limited power source and are usually deployed in hostile and harsh environments. The faulty nodes might cause incorrect data sensing, wrong data transmission, and insufficient data processing. A node is considered faulty if the threshold limit of its battery power is reached, its microcontroller fails, or its transmitter circuit fails to function correctly [123], [124] [125].

In routing algorithms, a new node must replace the faulty node. Otherwise, its responsibility needs to be shared by another healthy node [126]. Four main nodes are often used in the architecture of clustered routing protocols: the sink node (BS), which delivers the monitored data to the control system; the central nodes, which might be gateway or forwarder nodes; the CH, which is responsible for data transmission to the BS or a central node; and the cluster member that senses the network area. All these nodes might be damaged due to unexpected events such as fire incidents, resulting in a faulty node and thus losing the acquired data.

1) CHALLENGES OF FTRA IN FIRE INCIDENTS

Fault-Tolerance Routing Algorithms (FTRA) are essential in ensuring network connections, particularly in emergencies such as fire incidents. However, in such scenarios, these algorithms might face multiple challenges:

- **Dynamic Network Topology**: The network topology during fire incidents may change rapidly due to communication infrastructure damage. Such dynamic changes

TABLE 6. Properties of the CH selection techniques for the reviewed algorithms.

Ref. /protocol/Year	Type	Used Technique	CH Selection Criteria	Complexity	Simulation Environment	Advantages	Drawbacks
[91] **LEACH 2002**	Traditional	Non	More residual energy and not chosen as CH recently	Moderate $O(n)$	Network Simulator	Low-energy networking; load dividing among nodes	Randomized rotation of the CH; limited scalability
[92] **EDFCM 2010**	Traditional	Non	One-step energy consumption forecast	Moderate	MATLAB	Optimal number of CHs; prolonged lifetime; reliable transmission	No impact on the cluster's size and location in the CH selection algorithm
[93] **I-LEACH 2013**	Traditional	Non	Maximum residual energy, more neighbors, and a lower distance from BS	Low	MATLAB	Improved average energy consumption; increased lifetime; not cost-effective	Lower stability
[94] **Multi-level LEACH 2014**	Traditional	Non	Level1: randomly Level2 and Level3: highest residual energy and nearest to the BS	Low	NS3	Improve energy efficiency; maximize the lifetime	Limited scalability; high transmission delay; consumed high energy
[95] **PASCCC 2014**	Traditional	Non	Randomized CH election	High	N/A	Handle packet congestion; congestion detection; good data scheduling	High network Complexity; irregular CH distribution; random CH selection
[96] **MLRC 2016**	Traditional	Non	Residual energy and closer to the BS	Low O *(1)*, 1 is a single node	NS2	Reduced control message number; energy consumption reduction	Nonuniform CHs distribution; the fitting parameters for CHs selection were not considered
[97] **O-LEACH 2023**	Traditional	Non	Energy threshold	N/A	MATLAB	Prolongs the network lifetime; minimize he energy loss	Limited scalability
[98] **LEACH-FL 2010**	Optimized	Fuzzy logic	Residual energy, distance from BS, and node degree	Moderate $O(n)$	MATLAB	Energy consumption reduction; maximizing lifetime; improved security	One-hop communications led to limited scalability
[99] **PSO 2014**	Optimized	Particle Swarm Optimization (PSO)	Hop count and transmission distance	High	MATLAB+ C programming language	Performing better in terms of network lifespan, number of inactive sensors, and overall data packet transmission	High hops number and long-haul transmission caused energy exhausting
[100] **DUCF 2016**	Optimized	Fuzzy logic	Residual energy, node's degree, and distance from BS	High $O(n^2)$	MATLAB	Improving network lifetime and load balancing	Insufficient fitting criteria for computing the CH roles
[101] **BAFSA 2017**	Optimized	Swarm Optimization: AFSA	Energy and end-to-end delay	High $O(n^2)$	N/A	Fast convergence, good local search capabilities, fault-tolerant scheme	The fault tolerance scheme insufficient for sudden node loss
[102] **SCHFTL 2018**	Optimized	Fuzzy logic	Level 1: Randomly; Level 2: residual energy, centrality, communication quality, total delay, distance to the BS, and the DoS attacks; level3: residual energy and distance to the BS	High	MATLAB	Reduce data overhead and energy consumption	No metrics for electing the optimal CH count
[103] **GATERP 2019**	Optimized	Genetic Algorithm	Energy, cluster energy cluster quality, and transmitting delay	High	MATLAB	Improve network performance in terms of energy efficiency, load balancing, network lifetime, and stability period	With increased numbers of nodes both delay and computational complexity is increased
[104] **SBHRA 2020**	Optimized	Swarm Optimization: ABC	Residual energy and distance	High	MATLAB	Partitioning clustering for optimum CH election; efficient routing	Requires a lot of planning for node's placement; not scalable
[105] **CRDA 2023**	Optimized	Swarm Optimization: ISFO	"Highest trust degree owned swelling"	High	NS2	Improved energy consumption and reliability. Decreasing the data redundancies, packet loss, and latency	Computational complexity

TABLE 6. ***(Continued.)*** **Properties of the CH selection techniques for the reviewed algorithms.**

[106] **EECPK-means 2016**	ML-Based	K-means and Midpoint Algorithm	Residual energy and Euclidean distance	High	MATLAB+ C programming language	An effective multi-hop communication link from CHs to BS; data loss avoidance; energy balance among sensor nodes	Low accuracy and high complexity
[107] **——— 2017**	ML-Based	Naïve Bayes Classifier	Residual energy and the sum of the Euclidean Distance of member nodes to CH	High $O(n*d*c)$, n: data points number d: features No. c: classes No.	MATLAB	Flexibility; efficient algorithm	Inefficient cluster formation procedure
[108] **BEST-MAC 2019**	ML-Based	Artificial Neural Network (ANN)	Battery backup	High	MATLAB	Energy efficiency and improved throughput	Collisions that led to communication overhead
[109] **G-MCCH 2023**	ML-Based	Grid-based Multi-Channel Clustering Hierarchy (G-MCCH)	Grid-based CH selection	Low	N/A	Improvements in throughput, delay, and loss	Lower performance in different scenarios and environments
[110] **OZEEP 2015**	Intra-Hybrid Approach	Fuzzy logic+ Genetic Algorithm	Node energy, node distance to the BS, node density, and node mobility	High	MATLAB+ NS2	Desirable choice for real-time applications; energy efficient; has very little packet loss	Missing data retransmissions and routes set up in the event of path segmentation
[111] **LEACH-CNN 2015**	Intra-Hybrid +Inter-Hybrid Approaches	Traditional + Convolution Neural Network (CNN)+ Optimization algorithm	Distance from BS, residual energy, and no. of neighboring nodes	Moderate $O(n)$	NS2	Balance the energy exhaustion for the network load; extend the network lifetime	Not scalable
[112] **ASLPR 2015**	Intra-Hybrid Approach	Simulated Annealing (SA)+ Genetic Algorithm (GA) and	Distance from BS, residual energy, number of previously became CH, and distance from other CHs	High	MATLAB	Enhanced network lifetime; energy consumption balancing	Required further computations to select optimal CHs; limited scalability
[113] **TE-ZSEP EZ-TDEEC 2020**	Intra-Hybrid Approaches	Traditional + Traditional	Energy and distance	N/A	MATLAB	Improved network stability, network lifetime, instability period, throughput, and residual energy	Scalability were not addressed
[114] **HFAPSO 2020**	Intra-Hybrid +Inter-Hybrid Approaches	Traditional + Particle Swarm Optimization (PSO)+ Firefly Algorithm (FA)	Residual energy and distance between CH and cluster members	High $O(n^2 t)$ $+O(nt)$	NS2	Balance the trade-off between network lifetime and computational cost; inexpensive computational cost	Higher architectural complexity; higher processing complexity
[115] **DBN 2022**	Inter-Hybrid Approach	Reinforcement Learning algorithm (RL)+ Mantaray Foraging Optimization algorithm (MRFO)	Distance, energy, delay, and traffic density	High $(n^0+2)\,n^1 \cdot o(n(m+mD+1))$ n: input size, m: iterations number, D: dimension	MATLAB	Routing and energy-balanced clustering are achieved; shortest path identification is introduced	Increased nodes' number will increase the time complexity
[116] **CNN-LEACH 2022**	Inter-Hybrid Approach	Traditional +ML-based (CNN)	Probability value and residual energy	Moderate $O(n)$	MATLAB	Efficient CH selection method; enhanced network lifetime	Too many CHs lead to network overload
[117] **E-CFSA 2023**	Intra-Hybrid Approach	Convolution Neural Network (CNN)+ K-Means	Energy consumption, node degree value, packet drop, and node speed	High	NS2 + Python	Decreased CHs' repetitive passage; increased cluster member longevity and stability; less overhead and packet loss rate	The existing noise signals affect the performance; computational complexity

could be challenging for fault tolerance algorithms to adapt to, resulting in inefficient routing decisions.

- **Link and Node Failures**: Fires can result in node and link failures, which would prevent the network

TABLE 7. A comparative summary of the CH selection surveys.

Study/ Year	Distribution	Publications Period	Surveyed Algorithms	CH Selection-Methods Taxonomy	Comparative Parameters	Conclusions	Recommendations
Mazumdar *et al.* [118] **2018**	Comprehensive analysis of different clustering properties in clustering protocols	2002-2018	17	• Random • Hybrid • Weight • Fuzzy	Unequal cluster size, Intra-cluster single hop, Inter-cluster multi-hop, Coverage aware, and Fault-tolerant	1. The multi-hop routing has significantly reduced the consumed energy; however, the network lifetime has decreased due to the hotspot issue 2. Fuzzy logic-based clustering showed relevance in terms of node degree, density, cluster formation energy, and cluster range computations 3. More balanced energy consumption is achieved in unequal clustering approaches since they can deal with the hotspot issue	1. A lot of interest should be paid to develop energy-aware communication routing protocols 2. The CH selection and cluster range computation should involve several metrics to yield better results
John *et al.* [119] **2019**	Analyzing several CH selection methods based on WSN energy awareness	2007-2018	50	• Clustering Techniques • Optimization Techniques • LEACH Techniques • Distributed Techniques	Energy, Scalability, QoS, Security, Lifetime, No. of alive nodes, No. of dead nodes, Throughput, and Network Scalability	1. Energy has been used as an important parameter for CH selection 2. The reviewed protocols required more effort to be energy-effective in the CH selection algorithm 3. MATLAB is the preferred implementation tool	Design an energy-aware CH-Selection routing technique that improves energy efficiency and network lifetime with less complexity and more scalability and can be applied in realistic applications
Rawat *et al.* [36] **2021**	The clustering protocols are categorized according to their clustering techniques and functionalities	2000-2021	82	• Traditional clustering • Fuzzy logic-based clustering • Heuristic-based clustering	Data transmission, CH rotation, Mobility, Topology, Deployment, Fuzzy output, Defuzzification method, Fuzzy interference method, Optimization objectives, and others	The hybrid design is the optimal solution to overcome the issues of routing and enhancing network performance	1. Future research might combine the advantages of the MAC layer with clustering protocols to extend the performance and network lifetime 2. The node mobility with a minimum overhead should be further explored 3. Application-specific algorithms must be produced in future research
Arulmurugan *et al.* [120] **2021**	A comparative analysis of the important CH selection methods	2012-2019	13	• Random • Probability • Hybrid	Cluster Head Distribution, Cluster Stability, Merits, and Demerits	1. Most of the CH selection methods depend on residual energy and reliability 2. Cluster stability is typically low for random-based clustering	An efficient technique must be considered for CH selection to eliminate the challenges in the reviewed algorithms, such as energy efficiency, security, and QoS
Ramya *et al.* [121] **2022**	Provide a comprehensive survey for the CHs schemes in WSN-IoT	2007-2022	85	• Optimization algorithms • Clustering algorithm • AI approaches • LEACH approaches • Other algorithms	Adopted methodology, Publication years, Features, Challenges, and Evaluation metrics	1. The optimized algorithms were commonly exploited in various studies 2. MATLAB is often employed as an implementation simulator 3. The ML algorithms can be utilized for trust detection, QoS, and enhancing transmission load	1. Future works for the CHs in the WSN-IoT domain should consider different research challenges and issues 2. A hybrid approach using the meta-heuristic optimization algorithm based on ML could further enhance CH selection in healthcare applications

TABLE 7. *(Continued.)* **A comparative summary of the CH selection surveys.**

Raj *et al.* [41] **2022**	Comparative review of various metaheuristic and non-metaheuristic algorithms for CH selection and cluster formation	2005-2021	98	• Metaheuristic method a) Hybrid b) Non-Hybrid • Non-metaheuristic method a) Hybrid b) Non-Hybrid	Mobility, Data Transmission, Heterogeneity, Network dimension, No. of nodes, Packet Length, Initial energy, BS location, Objectives, Advantages, Limitations, Future direction, Time Complexity (TC), and Space Complexity (SC)	1. The common challenges faced by WSNs are energy, security, and quality of service (QoS) 2. Deep learning techniques were achieved to solve packet-dropping problems in case of huge data	1. Develop a mechanism that could efficiently ensure data confidentiality, integrity, and minimum resource usage in WSN 2. It is essential to include machine learning techniques for better efficiency and performance
Prasad *et al.* [122] **2023**	Analyses the clustering process and the CH selection methods for the energy optimization-based protocols in WSNs and IoT	2001-2020	78	• Equal Clustering 1. Probabilistic a) Random, b) Hybrid, 2. Preset 3. Deterministic a) Weight based, b) Fuzzy based, c) Heuristic based, d) Compound • Unequal Clustering 1. Probabilistic a) Random, b) Hybrid 2. Preset 3. Deterministic a) Weight based, b) Fuzzy based, c) Heuristic based d) Compound	Key concept and Limitations	1. Finding the optimal energy optimization strategy for WSNs is challenging because protocols are designed to enhance performance 2. The major issues in the reviewed protocols are: instability in clustering, low network lifetime, high data loss, less security, poor network management, ineffective data collection, and increased response time	1. Concentration on coverage holes when designing and implementing routing protocols 2. Enhances the protocol's performance by using machine learning and artificial intelligent
This study 2024	Comparative review of the CH selection method based on the technique used to address the adaptivity to sudden CH loss in fire incidents	2002-2023	27	• Traditional Clustering Approach • Optimized Clustering 1. Fuzzy logic-Based Clustering 2. Nature-Inspired Clustering 3. Genetic Algorithm Clustering • ML- Based Clustering • Hybrid Clustering 1. Intra-Hybrid 2. Inter-Hybrid	Type, Used Technique, CH selection Criteria, Complexity, Simulation Environment, Advantages, and Drawbacks	1. All the reviewed algorithms are not adaptive to the sudden loss of high-energy CHs during fire incidents 2. MATLAB is the recommended simulator for the CH selection methods 3. Hybrid clustering is the optimum choice to solve the difficult clustering challenges; however, it increases the complexity	1. A fire-adaptive clustering scheme should be developed, which should guarantee data delivery even with the sudden loss of CHs 2. Decisions based algorithms should be further adopted to solve the routing hole problem and prevent packet loss 3. Further effort should be made to simplify the hybrid-based algorithms' complexity

from functioning normally. To maintain connectivity, fault tolerance algorithms must immediately recognize these failures and reroute traffic. However, the damage degree might cause several failures simultaneously exceeding the algorithm's ability to identify alternate routes.

- **Energy Efficiency**: During fire events, network nodes are often battery-dependent or dependent on other sources. To extend the operational duration of nodes, fault tolerance algorithms must incorporate energy-efficient routing. However, this necessity may conflict with the requirements for redundancy and quick communication.
- **QoS Considerations**: Fire incidents should include high-priority communication with emergency response groups. Fault tolerance algorithms should balance maintaining communication and ensuring crucial data prty. Therefore, complex routing decisions might be needed.
- **Real-time Decision-Making**: Real-time decision-making is necessary during fire situations; thus, fault tolerance algorithms should rapidly respond to changing situations. For emergency response activities, delays in route computation or decision-making might have serious consequences.
- **Communication Infrastructure Damage**: Fires might physically harm communication infrastructure, including cellular towers and data centers. Fault tolerance algorithms may require consideration of alternative communication forms, such as ad-hoc networks, satellite connections, or mesh networks, which might provide further technological challenges.

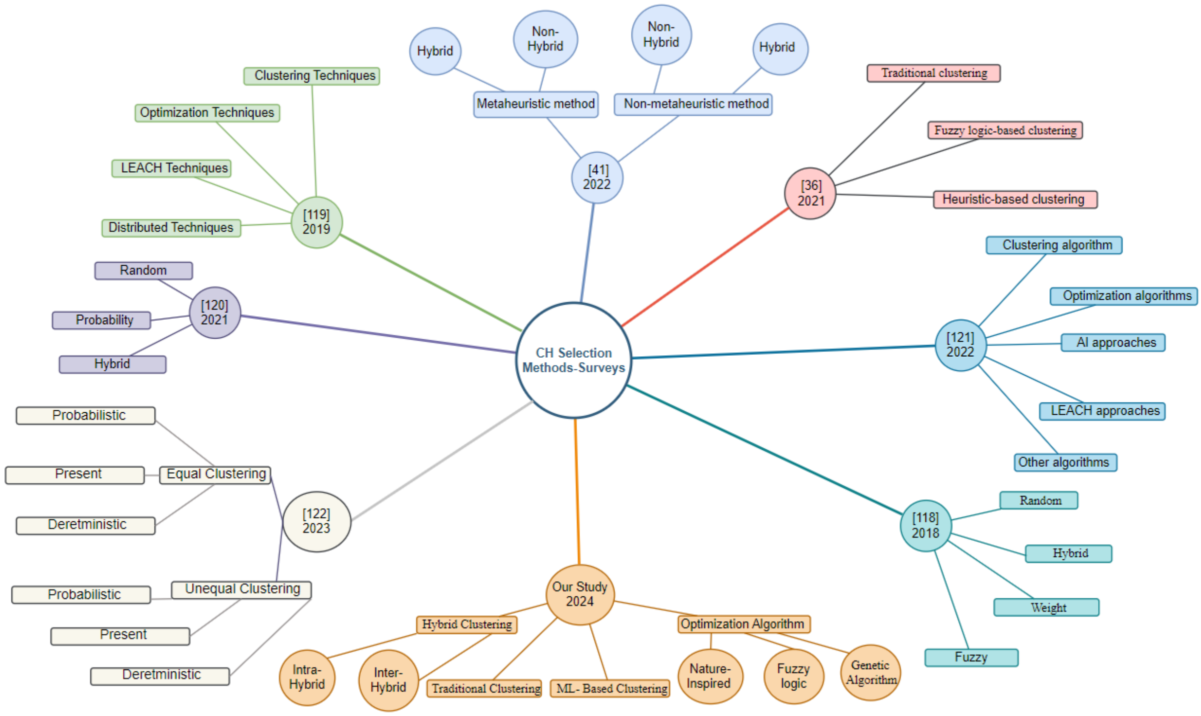

FIGURE 10. Classification comparison with the State-of-the-Art CH-Selection Surveys.

- **Incomplete Information**: Fires can lead to partial or complete loss of communication with certain network components. Fault tolerance algorithms heavily rely on accurate information about the network state. Incomplete and/or outdated information may result in network segmentation or inefficient routing decisions.
- **Congestion and Load Balancing**: Network congestion may occur when there is a surge in communication during fire events. All traffic should not be routed over just a few paths using fault tolerance algorithms because this may lead to more congestion and affect the performance of the whole network.
- **Data Security**: The sensitivity of transmitted information may increase during emergencies. Consequently, secure and encrypted routes should be achieved by fault tolerance algorithms to avoid unauthorized access to private information.

To overcome these challenges, routing protocol developers are invited to design powerful fault tolerance algorithms that consider the particularities of fire accidents and other emergencies. These algorithms attempt to develop reliable, robust, and effective communication networks even in rapidly changing topologies and unexpected conditions.

2) LIMITATIONS OF FTRA IN FIRE INCIDENTS

Many fault-tolerance routing algorithms are developed to detect faulty nodes. However, if the failure is due to fire incidents, these algorithms need to meet certain requirements to recover the faulty nodes properly. The key limitations on fault tolerance routing algorithms that prevent them from operating efficiently in fire conditions are outlined below:

- **Selected Parameters**: In fault-tolerance routing approaches, the parameters used to replace the faulty node, such as residual energy, node degree, delay between nodes, nearest distance, traffic, number of neighbor nodes, and probability value, are inaccurate for replacing the burned node in fire occurrences. It is essential to examine the temperature level and the distance from the burnt node for the alternate candidate node to avoid burning quickly by the same fires, as well as check the residual energy. Accordingly, the significant parameters that should be considered while replacing the burned node are residual energy, the largest distance from the burned node, and the temperature level.
- **Predefined Backup Nodes**: Some fault tolerance algorithms predefine an energy-efficient backup or spire node(s) to replace the faulty node to reduce the amount of energy and time needed to select another healthy node. However, a predefined node strategy is inefficient in the case of fire incidents because fire incidents require real-time decision-making. Accordingly, for fault node replacement, it is important to recognize the real-time status of the alternate candidate node based on the fire progress in terms of the temperature level and distance from the bunt node before replacing it with the burned nodes.
- **For One-Node Type**: As mentioned previously, four node types are usually deployed in clustered routing

TABLE 8. **The summary of ftras with significant limitations in fire incidents.**

Reference	Methodology	Objectives	Simulation Tool	Limitations in Fire Incidents			
				Selected Parameters	Predefined Backup Nodes	For One-Node Type	Detection Without Recovery
Rui *et al.* [127]	Particle Swarm Optimization	Self-adaptive and fault-tolerant routing for WSNs in microgrids to prolong network lifetime	MATLAB	✓	-	-	-
Azharuddin *et al.* [128]	Distributed clustering and routing algorithms	Energy efficient fault-tolerant and sudden CH fault-tolerant	MATLAB	✓	✓	✓	-
Haseeb *et al.* [129]	A multi-facet routing mechanism	Fault tolerance, reliable, and energy-efficient data routing	NS2	✓	-	✓	-
Qiu *et al.* [130]	Informer Homed Routing (IHR)	Energy-aware fault tolerance method for WSN	C#	✓	✓	✓	-
Mansour *et al.* [131]	Moth Flame Optimization (MFO) and Social Spider Optimization (SSO)	Energy-aware fault-tolerant clustering to improve the survivability of WSNs	N/A	✓	-	✓	-
M *et al.* [132]	Genetical Swarm Optimization (FTGSO)	Improves the self-healing of the network capacity	MATLAB	✓	-	✓	-
Amutha *et al.* [133]	LSTM and AdaBoost Classifier	Early fault prediction and faulty data classification	MATLAB	-	-	-	✓
Razaque *et al.* [134]	Checkpoint	Sink node failure detection and recovery	NS2	-	✓	✓	
Cao *et al.* [135]	Kernel Extreme Learning Machine Optimized by The Improved ABC Algorithm (IABC-KELM)	A fault node diagnosis of the heterogeneous WSN	MATLAB	-	-	-	✓
Lu *et al.* [136]	Structured Directional de Bruijn Graph	Optimize network structure and enhance both speed and accuracy of routing failure issues	NS2	✓	✓	-	-
Kaur *et al.* [137]	The 3-Tier hard fault detection mechanism	Enhance fault detection accuracy and minimize the false alarm rate	NS2	✓	-	-	✓
Agarwal *et al.* [138]	Multi-objective-Deep Reinforcement-Learning (DRL)	Faulty node detection with less overhead and high accuracy	NS2	✓	-	✓	✓
Chanak *et al.* [139]	Fuzzy rule	Detect and reuse faulty nodes in WSNs according to their fault status	NS2	✓	-	-	-
Mahmood *et al.* [140]	Reinforcement Learning	Determine the efficient path for fault detection with minimum end-to-end latency	MATLAB	✓	✓	✓	-
Kamalesh *et al.* [141]	Support Vector Machine (SVM)	Failure detection and loss recovery	NS2	✓	✓	✓	-
Rahul *et al.* [142]	Fuzzy Rule	Fault tolerance with optimal CH and gateway selection	NS2	✓	-	-	-

algorithms, which are the BS, CHs, central nodes, and cluster members. Some fault-tolerance algorithms detect and recover only one node type, such as BS, CH, or the central node. For a reliable fault tolerance scheme in fire incidents, the algorithm should be able to detect and recover all node types in the network architecture to maintain network functionality.

- **Detection Without Recovery**: Some fault tolerance approaches are developed exclusively for fault node detection without recovery. However, for guaranteed data delivery to BS in fire incidents, both detection and recovery of the fault nodes should be considered.

Table 8 analyzes some relevant fault tolerance routing algorithms in terms of methodology, objectives, and simulation tools, as well as the existing limitations in fire incidents.

The numerical description of the simulation tools used in the reviewed protocols of the whole survey is organized in Fig. 11. MATLAB is the most common simulation tool used in routing protocols with 59%, followed by the Network Simulator version 2 (NS2) with 23%.

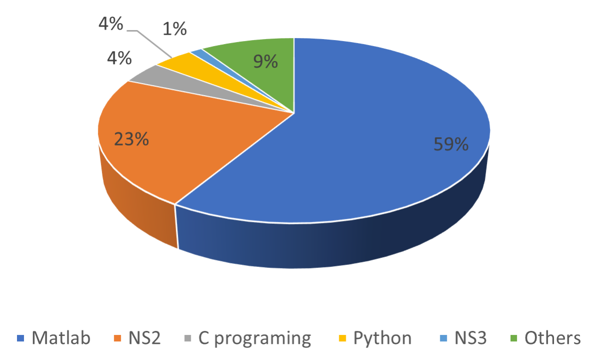

FIGURE 11. **The numerical description of the simulation tools used in the reviewed protocols of the survey.**

As a result, fire accidents have a significant and diverse influence on network performance metrics, impacting several crucial components that are essential to the reliability and efficacy of network operations. Network architecture can be deeply impacted by fire incidents, resulting in node failures and link damage. When routes become unstable and network infrastructure is destroyed, there is a greater chance of packet loss, which may significantly decrease the packet delivery ratio. Throughput is another important measure that is negatively impacted during fire incidents. The data transfer rate reduces as network congestion improves. This is exacerbated by the network's reduced ability because of faulty nodes and links. Furthermore, there might be a significant increase in the nodes' consumption of energy. In unstable environments, nodes may need to use more energy to remain connected and conduct complex routing calculations. Network segmentation results from fire incidents further play a critical role in performance degradation. Network fragmentation into isolated segments might prevent data flow over the network, affecting partially impacted regions of communication. This segmentation increases delay and lowers the overall reliability of the network by forcing it to perform significant reconfiguration efforts. Current routing protocols may be unable to adapt adequately to the suddenly changing environment, resulting in routing failures. Non-adaptive routing protocols may become ineffective, making the network unable to recover efficiently from distractions. This situation emphasizes the necessity for effective fault-tolerant routing and adaptive protocols able to preserve performance regardless of adverse conditions brought by fire incidents.

XI. CONCLUSION

WSNs have recently gained popularity due to their expanded applications in health care, environmental monitoring, earthquake and volcano prediction, security, intrusion detection, surveillance, and structural health monitoring. Cluster-based strategies are a successful solution for addressing the sensor's energy issue. This survey covered many clustering models and introduced a comprehensive overview of the clustering algorithms and their key characteristics. In addition, it discussed the essential aspects, contributions, benefits, and drawbacks of various clustering protocols to assist researchers in gaining a faster and deeper conception of the basic principles of various clustering models. However, the main objective of this survey is to evaluate the protocols' adaptivity for sudden fire incidents and determine if they can deliver data to BS properly even with a damaged network topology due to unpredictable events. Hence, the survey has concluded that the reviewed protocols suffer from one or multiple of the architecture challenges in sudden fire incidents. The major architecture challenges are the BS location, cluster insulation if the energy-effective CH loses, and central nodes losing. These challenges lead to the loss of a significant amount of monitored data, if not all, in fire incidents due to network segmentation. Moreover, the survey suggests various solutions that could be achieved to overcome these challenges, in terms of locating the BS outside the sensing field, integrating temperature sensing in the network's sensors, and developing an intelligent CH selection method that guarantees data routing and delivery even with the unexpected loss of CHs or central nodes. A new taxonomy for CH selection methods based on the used technique was introduced. Furthermore, the challenges and limitations that current fault tolerance routing algorithms suffer in fire incidents were further discussed, and the necessity of designing a powerful FTRA that is rabidly adaptive to the changing topology of the network was explored. Therefore, significant attention should be paid in the future to developing a fire adaptive clustering scheme that is compatible with unforeseen changes to achieve a successful data delivery process in sudden incidents, particularly indoor fires. The findings of this survey could be extended to other environments, such as dynamic/mobility scenarios, to highlight the potential applicability of the survey findings in other relevant scenarios.

REFERENCES

[1] M. K. Patra, "An architecture model for smart city using cognitive Internet of Things(CIoT)," in *Proc. 2nd Int. Conf. Electr., Comput. Commun. Technol. (ICECCT)*, Coimbatore, India, Feb. 2017, pp. 1–6.

[2] K. Staniec, *Radio Interfaces in the Internet of Things Systems*. Wroclaw, Poland: Springer, 2020.

[3] S. Iyengar, V. K. Gurbani, Y. Zhou, and S. Sharma, "Opportunistic prefetching of cellular Internet of Things (cIoT) device contexts," in *Proc. 27th Int. Conf. Comput. Commun. Netw. (ICCCN)*, Jul. 2018, pp. 1–6.

[4] D. Punia and R. Kumar, "Experimental characterization of routing protocols in urban vehicular communication," *Transp. Telecommun. J.*, vol. 20, no. 3, pp. 229–241, Jun. 2019.

[5] A. Whichi, M. Weber, I. Ketata, S. Sahnoun, and F. Derbel, "Simulation of wireless sensor nodes based on wake-up receivers," in *Proc. 18th Int. Multi-Conf. Syst., Signals Devices (SSD)*, Mar. 2021, pp. 235–240.

[6] X. Zhao, S. Ren, H. Quan, and Q. Gao, "Routing protocol for heterogeneous wireless sensor networks based on a modified grey wolf optimizer," *Sensors*, vol. 20, no. 3, pp. 1–18, 2020.

[7] F. T. AL-Dhief, R. C. Muniyandi, N. Sabri, M. Hamdan, N. M. A. Latiff, M. A. A. Albadr, M. H. H. Khairi, M. Hamzah, and S. Khan, "Forest fire detection using new routing protocol," *Sensors*, vol. 22, no. 20, p. 7745, Oct. 2022.

[8] P. S. Mann and S. Singh, "Artificial bee colony metaheuristic for energy-efficient clustering and routing in wireless sensor networks," *Soft Comput.*, vol. 21, no. 22, pp. 6699–6712, Nov. 2017.

[9] S. Begum, Y. Nianmin, S. B. H. Shah, A. Abdollahi, I. U. Khan, and L. Nawaf, "Source routing for distributed big data-based cognitive Internet of Things (CIoT)," *Wireless Commun. Mobile Comput.*, vol. 2021, no. 1, pp. 1–11, Jan. 2021.

[10] D. Mahmood, N. Javaid, S. Mahmood, S. Qureshi, A. M. Memon, and T. Zaman, "MODLEACH: A variant of LEACH for WSNs," in *Proc. 8th Int. Conf. Broadband Wireless Comput., Commun. Appl.*, Compiegne, France, Oct. 2013, pp. 158–163.

[11] H. Wu, X. Han, H. Zhu, C. Chen, and B. Yang, "An efficient opportunistic routing protocol with low latency for farm wireless sensor networks," *Electronics*, vol. 11, no. 13, p. 1936, Jun. 2022.

[12] B. Ahmad, M. Ahmed, N. Anjum, M. Ur Rehman, and N. Ramzan, "Energy efficient gateway based routing with maximized node coverage in a UAV assisted wireless sensor network," *PLoS ONE*, vol. 18, no. 12, Dec. 2023, Art. no. e0295615.

[13] C.-M. Yu and M.-L. Ku, "A novel balanced routing protocol for lifetime improvement in WSNs," in *Proc. IEEE Int. Conf. Consum. Electron. (ICCE)*, Jan. 2022, pp. 1–3.

[14] A. N. Sakib, M. Drieberg, S. Sarang, A. A. Aziz, N. T. T. Hang, and G. M. Stojanović, ''Energy-aware QoS MAC protocol based on prioritized-data and multi-hop routing for wireless sensor networks,'' *Sensors*, vol. 22, no. 7, p. 2598, Mar. 2022.

[15] F. Fanian and M. K. Rafsanjani, ''Cluster-based routing protocols in wireless sensor networks: A survey based on methodology,'' *J. Netw. Comput. Appl.*, vol. 142, pp. 111–142, Sep. 2019.

[16] M. Farsi, M. A. Elhosseini, M. Badawy, H. A. Ali, and H. Z. Eldin, ''Deployment techniques in wireless sensor networks, coverage and connectivity: A survey,'' *IEEE Access*, vol. 7, pp. 28940–28954, 2019.

[17] A. Sgueglia, A. Di Sorbo, C. A. Visaggio, and G. Canfora, ''A systematic literature review of IoT time series anomaly detection solutions,'' *Future Gener. Comput. Syst.*, vol. 134, pp. 170–186, Sep. 2022.

[18] B. Kadri, B. Bouyeddou, and D. Moussaoui, ''Early fire detection system using wireless sensor networks,'' in *Proc. Int. Conf. Appl. Smart Syst. (ICASS)*, Nov. 2018, pp. 1–4.

[19] U. Dampage, L. Bandaranayake, R. Wanasinghe, K. Kottahachchi, and B. Jayasanka, ''Forest fire detection system using wireless sensor networks and machine learning,'' *Sci. Rep.*, vol. 12, no. 1, pp. 1–12, Jan. 2022.

[20] X. Ren, C. Li, X. Ma, F. Chen, H. Wang, A. Sharma, G. S. Gaba, and M. Masud, ''Design of multi-information fusion based intelligent electrical fire detection system for green buildings,'' *Sustainability*, vol. 13, no. 6, p. 3405, Mar. 2021. [Online]. Available: https://www.mdpi.com/2071-1050/13/6/3405

[21] H. Fang, S. Lo, and J. T. Y. Lo, ''Building fire evacuation: An IoT-aided perspective in the 5G era,'' *Buildings*, vol. 11, no. 12, p. 643, Dec. 2021. [Online]. Available: https://www.mdpi.com/2075-5309/11/12/643

[22] *World Fire Statistics. International Association of Fire and Rescue Services*, C. O. W, Center for Fire Statistics of CTIF, Gaithersburg, MD, USA, 2023, no. 25.

[23] N. N. A. Qubbaj, A. A. Taleb, and W. Salameh, ''LEACH based protocols: A survey,'' *Adv. Sci., Technol. Eng. Syst. J.*, vol. 5, no. 6, pp. 1258–1266, Dec. 2020.

[24] S. P. Singh and S. C. Sharma, ''A survey on cluster based routing protocols in wireless sensor networks,'' *Proc. Comput. Sci.*, vol. 45, pp. 687–695, Jan. 2015.

[25] S. I. Shree, M. Karthiga, and C. Mariyammal, ''Improving congestion control in WSN by multipath routing with priority based scheduling,'' in *Proc. Int. Conf. Inventive Syst. Control (ICISC)*, Coimbatore, India, Jan. 2017, pp. 1–6.

[26] W. A. Hussein, B. M. Ali, M. Rasid, and F. Hashim, ''Smart geographical routing protocol achieving high QoS and energy efficiency based for wireless multimedia sensor networks,'' *Egyptian Informat. J.*, vol. 23, no. 2, pp. 225–238, Jul. 2022.

[27] P. Rawat and S. Chauhan, ''Clustering protocols in wireless sensor network: A survey, classification, issues, and future directions,'' *Comput. Sci. Rev.*, vol. 40, May 2021, Art. no. 100396.

[28] I. Daanoune, B. Abdennaceur, and A. Ballouk, ''A comprehensive survey on LEACH-based clustering routing protocols in wireless sensor networks,'' *Ad Hoc Netw.*, vol. 114, Apr. 2021, Art. no. 102409.

[29] A. I. Al-Sulaifanie, B. K. Al-Sulaifanie, and S. Biswas, ''Recent trends in clustering algorithms for wireless sensor networks: A comprehensive review,'' *Comput. Commun.*, vol. 191, pp. 395–424, Jul. 2022.

[30] A. E. Ezugwu, A. M. Ikotun, O. O. Oyelade, L. Abualigah, J. O. Agushaka, C. I. Eke, and A. A. Akinyelu, ''A comprehensive survey of clustering algorithms: State-of-the-art machine learning applications, taxonomy, challenges, and future research prospects,'' *Eng. Appl. Artif. Intell.*, vol. 110, Apr. 2022, Art. no. 104743.

[31] M. S. Gunjal and P. H. Kulkarni, ''Survey on various aspects of clustering in wireless sensor networks employing classical, optimization, and machine learning techniques,'' *Int. J. Recent Innov. Trends Comput. Commun.*, vol. 11, no. 5s, pp. 345–356, Jun. 2023.

[32] K. Guleria and A. K. Verma, ''Comprehensive review for energy efficient hierarchical routing protocols on wireless sensor networks,'' *Wireless Netw.*, vol. 25, no. 3, pp. 1159–1183, Apr. 2019.

[33] H. Khlaifi, A. Zrelli, and T. Ezzedine, ''Routing protocols for a border monitoring application,'' in *Proc. Int. Conf. Internet Things, Embedded Syst. Commun. (IINTEC)*, Tunis, Tunisia, Dec. 2019, pp. 1–6.

[34] W. Guo and W. Zhang, ''A survey on intelligent routing protocols in wireless sensor networks,'' *J. Netw. Comput. Appl.*, vol. 38, pp. 185–201, Jan. 2014.

[35] A. H. Allam, M. Taha, and H. H. Zayed, ''Enhanced zone-based energy aware data collection protocol for WSNs (E-ZEAL),'' *J. King Saud Univ. Comput. Inf. Sci.*, vol. 34, no. 2, pp. 36–46, Feb. 2022.

[36] P. Rawat and S. Chauhan, ''A survey on clustering protocols in wireless sensor network: Taxonomy, comparison, and future scope,'' *J. Ambient Intell. Humanized Comput.*, vol. 14, no. 3, pp. 1543–1589, Mar. 2023.

[37] Y. Cheng, M. Jiang, and D. Yuan, ''Novel clustering algorithms based on improved artificial fish swarm algorithm,'' in *Proc. 6th Int. Conf. Fuzzy Syst. Knowl. Discovery*, vol. 3, Tianjin, China, Aug. 2009, pp. 141–145.

[38] Z. Ullah, ''A survey on hybrid, energy efficient and distributed (HEED) based energy efficient clustering protocols for wireless sensor networks,'' *Wireless Pers. Commun.*, vol. 112, no. 4, pp. 2685–2713, Jun. 2020.

[39] R. Kumar and D. Kumar, ''Multi-objective fractional artificial bee colony algorithm to energy aware routing protocol in wireless sensor network,'' *Wireless Netw.*, vol. 22, no. 5, pp. 1461–1474, Jul. 2016.

[40] L. Chan, K. G. Chavez, H. Rudolph, and A. Hourani, ''Hierarchical routing protocols for wireless sensor network: A compressive survey,'' *Wireless Netw.*, vol. 26, no. 5, pp. 3291–3314, Jul. 2020.

[41] B. Raj, I. Ahmedy, M. Y. I. Idris, and R. Md. Noor, ''A survey on cluster head selection and cluster formation methods in wireless sensor networks,'' *Wireless Commun. Mobile Comput.*, vol. 2022, pp. 1–53, Mar. 2022.

[42] A. Tripathi, H. P. Gupta, T. Dutta, R. Mishra, K. K. Shukla, and S. Jit, ''Coverage and connectivity in WSNs: A survey, research issues and challenges,'' *IEEE Access*, vol. 6, pp. 26971–26992, 2018.

[43] S. Tyagi and N. Kumar, ''A systematic review on clustering and routing techniques based upon LEACH protocol for wireless sensor networks,'' *J. Netw. Comput. Appl.*, vol. 36, no. 2, pp. 623–645, Mar. 2013.

[44] J. N. Al-Karaki and A. E. Kamal, ''Routing techniques in wireless sensor networks: A survey,'' *IEEE Wireless Commun.*, vol. 11, no. 6, pp. 6–28, Dec. 2004.

[45] D. Xu and Y. Tian, ''A comprehensive survey of clustering algorithms,'' *Ann. Data Sci.*, vol. 2, no. 2, pp. 165–193, Jun. 2015.

[46] M. Nighot, ''Design issues of wireless sensor network and open research challenges,'' *EAI Endorsed Trans. Energy Web*, vol. 8, Jul. 2018, Art. no. 166549.

[47] P. Srividya and L. N. Devi, ''An optimal cluster & trusted path for routing formation and classification of intrusion using the machine learning classification approach in WSN,'' *Global Transitions Proc.*, vol. 3, no. 1, pp. 317–325, Jun. 2022.

[48] G. Kia and A. Hassanzadeh, ''A multi-threshold long life time protocol with consistent performance for wireless sensor networks,'' *AEU Int. J. Electron. Commun.*, vol. 101, pp. 114–127, Mar. 2019.

[49] Y.-D. Yao, C. Wang, X. Li, Z.-B. Zeng, B.-Z. Zhao, Z. Su, and H.-C. Li, ''Multihop clustering routing protocol based on improved coronavirus herd immunity optimizer and Q-learning in WSNs,'' *IEEE Sensors J.*, vol. 23, no. 2, pp. 1645–1659, Jan. 2023.

[50] P. Rawat and S. Chauhan, ''Particle swarm optimization-based energy efficient clustering protocol in wireless sensor network,'' *Neural Comput. Appl.*, vol. 33, no. 21, pp. 14147–14165, Nov. 2021.

[51] I. Daanoune, A. Baghdad, and W. Ullah, ''Adaptive coding clustered routing protocol for energy efficient and reliable WSN,'' *Phys. Commun.*, vol. 25, Jun. 2022, Art. no. 101705.

[52] B. Han, F. Ran, J. Li, L. Yan, H. Shen, and A. Li, ''A novel adaptive cluster based routing protocol for energy-harvestingwireless sensor networks,'' *Sensors*, vol. 22, no. 4, pp. 1–16, 2022.

[53] S. Sridharan, S. Venkatraman, and S. P. Raja, ''A novel lie hypergraph based lifetime enhancement routing protocol for environmental monitoring in wireless sensor networks,'' *IEEE Trans. Computat. Social Syst.*, vol. 11, no. 2, pp. 2070–2080, Jun. 2024.

[54] S. Bharany, S. Sharma, S. Badotra, O. I. Khalaf, Y. Alotaibi, S. Alghamdi, and F. Alassery, ''Energy-efficient clustering scheme for flying ad-hoc networks using an optimized LEACH protocol,'' *Energies*, vol. 14, no. 19, p. 6016, Sep. 2021.

[55] I. Ullah, T. Hussain, A. Khan, I. Ali, F. Ali, and C. Choi, ''Analyzing the impacts of node density and speed on routing protocol performance in firefighting applications,'' *Fire Ecol.*, vol. 19, no. 1, p. 62, 2023.

[56] R. B. Pedditi and K. Debasis, ''Energy efficient routing protocol for an IoT-based WSN system to detect forest fires,'' *Appl. Sci.*, vol. 13, no. 5, p. 3026, Feb. 2023. [Online]. Available: https://www.mdpi.com/2076-3417/13/5/3026

[57] A. Benelhouri, H. Idrissi-Saba, and J. Antari, "An improved gateway-based energy-aware multi-hop routing protocol for enhancing lifetime and throughput in heterogeneous WSNs," *Simul. Model. Pract. Theory*, vol. 116, Apr. 2022, Art. no. 102471. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1569190X21001581

[58] G. Zhao, Y. Li, and L. Zhang, "SSEEP: state-switchable energy-conserving routing protocol for heterogeneous wireless sensor networks," in *Proc. IEEE 9th Int. Conf. Electron. Inf. Emergency Commun. (ICEIEC)*, Beijing, China, Jul. 2019, pp. 1–4.

[59] P. K. Chithaluru, M. S. Khan, M. Kumar, and T. Stephan, "ETH-LEACH: An energy enhanced threshold routing protocol for WSNs," *Int. J. Commun. Syst.*, vol. 34, no. 12, Aug. 2021, Art. no. e4881.

[60] I. Diakhate, B. Niang, A. D. Kora, and R. M. Faye, "Optimizing the energy consumption of WSN by using energy efficient routing protocol using Dijkstra algorithm," in *Proc. 2nd Int. Conf. Electron. Electr. Eng. Intell. Syst. (ICE3IS)*, Nov. 2022, pp. 147–152.

[61] F. Jibreel, E. Tuyishimire, and M. I. Daabo, "An enhanced heterogeneous gateway-based energy-aware multi-hop routing protocol for wireless sensor networks," *Information*, vol. 13, no. 4, p. 166, Mar. 2022.

[62] Y. Zhang, L. Liu, M. Wang, J. Wu, and H. Huang, "An improved routing protocol for raw data collection in multihop wireless sensor networks," *Comput. Commun.*, vol. 188, pp. 66–80, Apr. 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0140366422000597

[63] M. K. Khan, M. Shiraz, K. Z. Ghafoor, S. Khan, A. S. Sadiq, and G. Ahmed, "EE-MRP: Energy-Efficient multistage routing protocol for wireless sensor networks," *Wireless Commun. Mobile Comput.*, vol. 2018, no. 1, pp. 1–14, Jan. 2018.

[64] M. S. Azizi and M. L. Hasnaoui, "An energy efficient clustering protocol for homogeneous and heterogeneous wireless sensor network," in *Proc. 2nd Int. Conf. Netw., Inf. Syst. Secur.*, Mar. 2019, pp. 1–6.

[65] P. Kaur, K. Kaur, K. Singh, and S. Kim, "Early forest fire detection using a protocol for energy-efficient clustering with weighted-based optimization in wireless sensor networks," *Appl. Sci.*, vol. 13, no. 5, p. 3048, Feb. 2023.

[66] Y. Zhang, X. Zhang, S. Ning, J. Gao, and Y. Liu, "Energy-efficient multilevel heterogeneous routing protocol for wireless sensor networks," *IEEE Access*, vol. 7, pp. 55873–55884, 2019.

[67] M. K. Alom, A. Hossan, and P. K. Choudhury, "Improved zonal stable election protocol (IZ-SEP) for hierarchical clustering in heterogeneous wireless sensor networks," *e-Prime Adv. Electr. Eng., Electron. Energy*, vol. 2, Jan. 2022, Art. no. 100048.

[68] A. S. Toor and A. K. Jain, "Energy aware cluster based multi-hop energy efficient routing protocol using multiple mobile nodes (MEACBM) in wireless sensor networks," *AEU Int. J. Electron. Commun.*, vol. 102, pp. 41–53, Apr. 2019.

[69] T. Gui, F. Wang, C. Ma, and D. E. Wilkins, "On cluster head selection in monkey-inspired optimization based routing protocol for WSNs," in *Proc. Int. Conf. Comput., Netw. Commun. (ICNC)*, Feb. 2019, pp. 126–130.

[70] H. Faris, M. K. Mahmood, O. A. Alomari, and A. Elnagar, "Optimization of head cluster selection in WSN by human-based optimization techniques," *Comput., Mater. Continua*, vol. 72, no. 3, pp. 5643–5661, 2022.

[71] S. Yalçın and E. Erdem, "TEO-MCRP: Thermal exchange optimization-based clustering routing protocol with a mobile sink for wireless sensor networks," *J. King Saud Univ. Comput. Inf. Sci.*, vol. 34, no. 8, pp. 5333–5348, Sep. 2022.

[72] A. Benelhouri, H. Idrissi-Saba, and J. Antari, "An evolutionary routing protocol for load balancing and QoS enhancement in IoT enabled heterogeneous WSNs," *Simul. Model. Pract. Theory*, vol. 124, Apr. 2023, Art. no. 102729.

[73] S. Singh, A. S. Nandan, G. Sikka, A. Malik, and A. Vidyarthi, "A secure energy-efficient routing protocol for disease data transmission using IoMT," *Comput. Electr. Eng.*, vol. 101, Jul. 2022, Art. no. 108113.

[74] N. Moussa, E. Nurellari, K. Azbeg, A. Boulouz, K. Afdel, L. Koutti, M. B. Salah, and A. El Belrhiti El Alaoui, "A reinforcement learning based routing protocol for software-defined networking enabled wireless sensor network forest fire detection," *Future Gener. Comput. Syst.*, vol. 149, pp. 478–493, Dec. 2023.

[75] A. A. Baradaran and K. Navi, "HQCA-WSN: High-quality clustering algorithm and optimal cluster head selection using fuzzy logic in wireless sensor networks," *Fuzzy Sets Syst.*, vol. 389, pp. 114–144, Jun. 2020.

[76] M. Biabani, H. Fotouhi, and N. Yazdani, "An energy-efficient evolutionary clustering technique for disaster management in IoT networks," *Sensors*, vol. 20, no. 9, p. 2647, May 2020.

[77] K. P. Rani, P. Sreedevi, E. Poornima, and T. S. Sri, "FTOR-mod PSO: A fault tolerance and an optimal relay node selection algorithm for wireless sensor networks using modified PSO," *Knowl.-Based Syst.*, vol. 272, Jul. 2023, Art. no. 110583.

[78] S. Singh, D. Garg, Manju, and A. Malik, "A novel cluster head selection algorithm based IoT enabled heterogeneous WSNs distributed architecture for smart city," *Microprocessors Microsyst.*, vol. 101, Sep. 2023, Art. no. 104892.

[79] M. K. Khan, M. Shiraz, Q. Shaheen, S. A. Butt, R. Akhtar, M. A. Khan, and W. Changda, "Hierarchical routing protocols for wireless sensor networks: Functional and performance analysis," *J. Sensors*, vol. 2021, no. 1, pp. 1–18, Jan. 2021.

[80] H. P. Luong, S. H. Nguyen, H. L. Vu, and B. Q. Vo, "One-hop vs. multi-hop broadcast protocol for DSRC safety applications," in *Proc. IEEE Int. Symp. World Wireless, Mobile Multimedia Netw.*, Jun. 2014, pp. 1–3.

[81] P. Maurya and A. Kaur, "A survey on descendants of LEACH protocol," *Int. J. Inf. Eng. Electron. Bus.*, vol. 8, no. 2, pp. 46–58, Mar. 2016.

[82] R. Thalore, P. P. Bhattacharya, and M. K. Jha, "Performance comparison of homogeneous and heterogeneous 3D wireless sensor networks," *J. Telecommun. Inf. Technol.*, vol. 2, no. 2017, pp. 32–37, Jul. 2017.

[83] A. Cenedese, M. Luvisotto, and G. Michieletto, "Distributed clustering strategies in industrial wireless sensor networks," *IEEE Trans. Ind. Informat.*, vol. 13, no. 1, pp. 228–237, Feb. 2017.

[84] R. Pachlor and D. Shrimankar, "VCH-ECCR: A centralized routing protocol for wireless sensor networks," *J. Sensors*, vol. 2017, pp. 1–10, Jan. 2017.

[85] L. Karim, N. Nasser, and N. Khan, "Recent advancement in sensor web architectures and applications," in *Proc. 1st Kuwait Conf. e-Services e-Syst.*, Nov. 2009, pp. 1–7.

[86] A. Ali, A. Ali, F. Masud, M. K. Bashir, A. H. Zahid, G. Mustafa, and Z. Ali, "Enhanced fuzzy logic zone stable election protocol for cluster head election (E-FLZSEPFCH) and multipath routing in wireless sensor networks," *Ain Shams Eng. J.*, vol. 15, no. 2, Feb. 2024, Art. no. 102356.

[87] G. Santhosh and K. V. Prasad, "Energy optimization routing for hierarchical cluster based WSN using artificial bee colony," *Meas., Sensors*, vol. 29, Oct. 2023, Art. no. 100848.

[88] T. G. Nguyen, C. So-In, and N. G. Nguyen, "Two energy-efficient cluster head selection techniques based on distance for wireless sensor networks," in *Proc. Int. Comput. Sci. Eng. Conf. (ICSEC)*, Khon Kaen, Thailand, Jul. 2014, pp. 33–38.

[89] A. Shahraki, A. Taherkordi, Ø. Haugen, and F. Eliassen, "Clustering objectives in wireless sensor networks: A survey and research direction analysis," *Comput. Netw.*, vol. 180, Oct. 2020, Art. no. 107376.

[90] D. Gurusamy and S. Abas, "Modified clustering algorithms for energy harvesting wireless sensor networks—A survey," in *Proc. 21st Int. Arab Conf. Inf. Technol. (ACIT)*, Giza, Egypt, Nov. 2020, pp. 1–11.

[91] W. B. Heinzelman, A. P. Chandrakasan, and H. Balakrishnan, "An application-specific protocol architecture for wireless microsensor networks," *IEEE Trans. Wireless Commun.*, vol. 1, no. 4, pp. 660–670, Oct. 2002.

[92] H. Zhou, Y. Wu, Y. Hu, and G. Xie, "A novel stable selection and reliable transmission protocol for clustered heterogeneous wireless sensor networks," *Comput. Commun.*, vol. 33, no. 15, pp. 1843–1849, Sep. 2010.

[93] Z. Beiranvand, A. Patooghy, and M. Fazeli, "I-LEACH: An efficient routing algorithm to improve performance & to reduce energy consumption in wireless sensor networks," in *Proc. 5th Conf. Inf. Knowl. Technol.*, Shiraz, Iran, May 2013, pp. 13–18.

[94] R. K. Kodali, S. K. Gundabathula, and L. Boppana, "Multi level secure LEACH protocol model using NS-3," in *Proc. 1st Int. Conf. Netw. Soft Comput. (ICNSC)*, Guntur, India, Aug. 2014, pp. 198–202.

[95] M. A. Jan, P. Nanda, X. He, and R. P. Liu, "PASCCC: Priority-based application-specific congestion control clustering protocol," *Comput. Netw.*, vol. 74, pp. 92–102, Dec. 2014.

[96] M. Sabet and H. Naji, "An energy efficient multi-level route-aware clustering algorithm for wireless sensor networks: A self-organized approach," *Comput. Electr. Eng.*, vol. 56, pp. 399–417, Nov. 2016.

[97] S. Chen, Y. Chen, Y. Huang, and W. Wei, "Optimization of LEACH routing protocol algorithm," in *Proc. IEEE 3rd Int. Conf. Power, Electron. Comput. Appl. (ICPECA)*, Jan. 2023, pp. 1105–1108.

[98] Y.-q. Zhang and L. Wei, "Improving the LEACH protocol for wireless sensor networks," in *Proc. IET Int. Conf. Wireless Sensor Netw. (IET-WSN)*, Nov. 2010, pp. 355–359.

[99] P. Kuila and P. K. Jana, "Energy efficient clustering and routing algorithms for wireless sensor networks: Particle swarm optimization approach," *Eng. Appl. Artif. Intell.*, vol. 33, pp. 127–140, Aug. 2014.

[100] B. Baranidharan and B. Santhi, "DUCF: Distributed load balancing unequal clustering in wireless sensor networks using fuzzy approach," *Appl. Soft Comput.*, vol. 40, pp. 495–506, Mar. 2016.

[101] P. Sengottuvelan and N. Prasath, "BAFSA: Breeding artificial fish swarm algorithm for optimal cluster head selection in wireless sensor networks," *Wireless Pers. Commun.*, vol. 94, no. 4, pp. 1979–1991, Jun. 2017.

[102] M. Ayati, M. H. Ghayyoumi, and A. Keshavarz-Mohammadiyan, "A fuzzy three-level clustering method for lifetime improvement of wireless sensor networks," *Ann. Telecommun.*, vol. 73, nos. 7–8, pp. 535–546, Aug. 2018.

[103] N. Mittal, U. Singh, and B. S. Sohi, "An energy-aware cluster-based stable protocol for wireless sensor networks," *Neural Comput. Appl.*, vol. 31, no. 11, pp. 7269–7286, Nov. 2019.

[104] A. S. Yadav, K. Khushboo, V. K. Singh, and D. S. Kushwaha, "Increasing efficiency of sensor nodes by clustering in section based hybrid routing protocol with artificial bee colony," *Proc. Comput. Sci.*, vol. 171, pp. 887–896, Jan. 2020.

[105] G. Ravi, M. Swamy Das, and K. Karmakonda, "Reliable cluster based data aggregation scheme for IoT network using hybrid deep learning techniques," *Meas., Sensors*, vol. 27, Jun. 2023, Art. no. 100744.

[106] A. Ray and D. De, "Energy efficient clustering protocol based on K-means (EECPK-means)-midpoint algorithm for enhanced network lifetime in wireless sensor network," *IET Wireless Sensor Syst.*, vol. 6, no. 6, pp. 181–191, Dec. 2016.

[107] V. Jafarizadeh, A. Keshavarzi, and T. Derikvand, "Efficient cluster head selection using Naïve Bayes classifier for wireless sensor networks," *Wireless Netw.*, vol. 23, no. 3, pp. 779–785, Apr. 2017.

[108] R. Kumar and M. Gangwar, "Improved BEST-MAC protocol for WSN using optimal cluster head selection," *Int. J. Inf. Technol.*, vol. 15, no. 2, pp. 859–875, Feb. 2023.

[109] M. Ridwan, T. Wahyono, A. Iriani, and R. Darmastuti, "Grid-based cluster head selection for improved performance in multi-channel clustering hierarchy," in *Proc. Int. Conf. Model. E-Inf. Res., Artif. Learn. Digit. Appl. (ICMERALDA)*, Nov. 2023, pp. 283–288.

[110] J. R. Srivastava and T. S. B. Sudarshan, "A genetic fuzzy system based optimized zone based energy efficient routing protocol for mobile sensor networks (OZEEP)," *Appl. Soft Comput.*, vol. 37, pp. 863–886, Dec. 2015.

[111] L. Shi, L. Mengyao, and X. Li, "WSN data fusion approach based on improved BP algorithm and clustering protocol," in *Proc. 27th Chin. Control Decis. Conf. (CCDC)*, Qingdao, China, May 2015, pp. 1450–1454.

[112] M. Shokouhifar and A. Jalali, "A new evolutionary based application specific routing protocol for clustered wireless sensor networks," *AEU Int. J. Electron. Commun.*, vol. 69, no. 1, pp. 432–441, Jan. 2015.

[113] F. A. Mohamed, E. S. Hassan, M. I. Dessouky, and A. S. Elsafrawey, "Performance enhancement routing protocols for heterogeneous WSNs," *Int. J. Commun. Syst.*, vol. 33, no. 4, Mar. 2020, Art. no. e4223.

[114] B. Pitchaimanickam and G. Murugaboopathi, "A hybrid firefly algorithm with particle swarm optimization for energy efficient optimal cluster head selection in wireless sensor networks," *Neural Comput. Appl.*, vol. 32, no. 12, pp. 7709–7723, Jun. 2020.

[115] G. Arya, A. Bagwari, and D. S. Chauhan, "Performance analysis of deep learning-based routing protocol for an efficient data transmission in 5G WSN communication," *IEEE Access*, vol. 10, pp. 9340–9356, 2022.

[116] H. K. Prajapati and R. Joshi, "Performance analysis of LEACH with deep learning in wireless sensor networks," *Int. J. Electron. Telecommun.*, vol. 68, pp. 799–805, Nov. 2022.

[117] D. Bisen, U. K. Lilhore, P. Manoharan, F. Dahan, O. Mzoughi, F. Hajjej, P. Saurabh, and K. Raahemifar, "A hybrid deep learning model using CNN and K-mean clustering for energy efficient modelling in mobile EdgeIoT," *Electronics*, vol. 12, no. 6, p. 1384, Mar. 2023.

[118] N. Mazumdar, S. Roy, and S. Nayak, "A survey on clustering approaches for wireless sensor networks," in *Proc. 2nd Int. Conf. Data Sci. Bus. Analytics (ICDSBA)*, Changsha, China, Sep. 2018, pp. 236–240.

[119] J. John and P. Rodrigues, "A survey of energy-aware cluster head selection techniques in wireless sensor network," *Evol. Intell.*, vol. 15, no. 2, pp. 1109–1121, Jun. 2022.

[120] A. Arulmurugan, S. F. Waris, and N. Bhagyalakshmi, "Analysis of cluster head selection methods in WSN," in *Proc. 6th Int. Conf. Inventive Comput. Technol. (ICICT)*, Coimbatore, India, Jan. 2021, pp. 114–119.

[121] R. Ramya and D. T. Brindha, "A comprehensive review on optimal cluster head selection in WSN-IoT," *Adv. Eng. Softw.*, vol. 171, Sep. 2022, Art. no. 103170.

[122] V. K. H. Prasad and S. Periyasamy, "Energy optimization-based clustering protocols in wireless sensor networks and Internet of Things-survey," *Int. J. Distrib. Sensor Netw.*, vol. 2023, pp. 1–18, Jan. 2023.

[123] I. Banerjee, P. Chanak, H. Rahaman, and T. Samanta, "Effective fault detection and routing scheme for wireless sensor networks," *Comput. Electr. Eng.*, vol. 40, no. 2, pp. 291–306, Feb. 2014.

[124] K. Zhao, S. Di, S. Li, X. Liang, Y. Zhai, J. Chen, K. Ouyang, F. Cappello, and Z. Chen, "FT-CNN: Algorithm-based fault tolerance for convolutional neural networks," *IEEE Trans. Parallel Distrib. Syst.*, vol. 32, no. 7, pp. 1677–1689, Jul. 2021.

[125] E. Rosas, F. Garay, and N. Hidalgo, "Context-aware self-adaptive routing for delay tolerant network in disaster scenarios," *Ad Hoc Netw.*, vol. 102, May 2020, Art. no. 102095.

[126] E. Moridi, M. Haghparast, M. Hosseinzadeh, and S. J. Jassbi, "Fault management frameworks in wireless sensor networks: A survey," *Comput. Commun.*, vol. 155, pp. 205–226, Apr. 2020.

[127] L. Rui, X. Wang, Y. Zhang, X. Wang, and X. Qiu, "A self-adaptive and fault-tolerant routing algorithm for wireless sensor networks in micro-grids," *Future Gener. Comput. Syst.*, vol. 100, pp. 35–45, Nov. 2019.

[128] M. Azharuddin, P. Kuila, and P. K. Jana, "Energy efficient fault tolerant clustering and routing algorithms for wireless sensor networks," *Comput. Electr. Eng.*, vol. 41, pp. 177–190, Jan. 2015.

[129] K. Haseeb, K. A. Bakar, A. H. Abdullah, A. Ahmed, T. Darwish, and F. Ullah, "A dynamic energy-aware fault tolerant routing protocol for wireless sensor networks," *Comput. Electr. Eng.*, vol. 56, pp. 557–575, Nov. 2016.

[130] M. Qiu, Z. Ming, J. Li, J. Liu, G. Quan, and Y. Zhu, "Informer homed routing fault tolerance mechanism for wireless sensor networks," *J. Syst. Archit.*, vol. 59, nos. 4–5, pp. 260–270, Apr. 2013.

[131] R. F. Mansour, S. A. Alsuhibany, S. Abdel-Khalek, R. Alharbi, T. Vaiyapuri, A. J. Obaid, and D. Gupta, "Energy aware fault tolerant clustering with routing protocol for improved survivability in wireless sensor networks," *Comput. Netw.*, vol. 212, Jul. 2022, Art. no. 109049.

[132] M. Shyama, A. S. Pillai, and A. Anpalagan, "Self-healing and optimal fault tolerant routing in wireless sensor networks using genetical swarm optimization," *Comput. Netw.*, vol. 217, Nov. 2022, Art. no. 109359.

[133] R. Amutha, G. G. Sivasankari, and K. R. Venugopal, "A prediction model for effective data aggregation materials and fault node classification in WSN," *Mater. Today, Proc.*, vol. 49, pp. 2962–2967, Jan. 2022.

[134] A. Razaque and K. Elleithy, "Robust sink failure avoidance protocol for wireless sensor networks," *Int. J. Adv. Res.*, vol. 2, no. 9, pp. 721–731, 2014.

[135] L. Cao, Y. Yue, and Y. Zhang, "A novel fault diagnosis strategy for heterogeneous wireless sensor networks," *J. Sensors*, vol. 2021, no. 1, pp. 1–18, Jan. 2021.

[136] C. Lu and D. Hu, "A fault-tolerant routing algorithm for wireless sensor networks based on the structured directional de Bruijn graph," *Cybern. Inf. Technol.*, vol. 16, no. 2, pp. 46–59, Jun. 2016.

[137] G. Kaur and P. Chanak, "An energy aware intelligent fault detection scheme for IoT-enabled WSNs," *IEEE Sensors J.*, vol. 22, no. 5, pp. 4722–4731, Mar. 2022.

[138] V. Agarwal, S. Tapaswi, and P. Chanak, "Intelligent fault-tolerance data routing scheme for IoT-enabled WSNs," *IEEE Internet Things J.*, vol. 9, no. 17, pp. 16332–16342, Sep. 2022.

[139] P. Chanak and I. Banerjee, "Fuzzy rule-based faulty node classification and management scheme for large scale wireless sensor networks," *Expert Syst. Appl.*, vol. 45, pp. 307–321, Mar. 2016.

[140] T. Mahmood, J. Li, Y. Pei, F. Akhtar, S. A. Butt, A. Ditta, and S. Qureshi, "An intelligent fault detection approach based on reinforcement learning system in wireless sensor network," *J. Supercomput.*, vol. 78, no. 3, pp. 3646–3675, Feb. 2022.

[141] S. Kamalesh and P. Ganesh Kumar, "Data aggregation in wireless sensor network using SVM-based failure detection and loss recovery," *J. Experim. Theor. Artif. Intell.*, vol. 29, no. 1, pp. 133–147, Jan. 2017.

[142] P. Rahul and B. Kaarthick, "An optimal cluster head and gateway node selection with fault tolerance," *Intell. Autom. Soft Comput.*, vol. 35, no. 2, pp. 1595–1609, 2023.

OLA KHUDHAIR ABBAS received the B.Sc. degree from the Computer Department, College of Engineering, University of Basrah, Iraq, in 2010, and the M.Sc. degree from the College of Computer Engineering, University of Technology, Iraq, in 2019. She is currently pursuing the Ph.D. degree with the College of Engineering, Universiti Tenaga Nasional (UNITEN). Since 2013, she has as a Lecturer at the General Directorate of Education in Misan Governorate, Iraqi Ministry of Education, Misan, Iraq. Her research interests include wireless sensor networks, routing protocols, machine learning, deep learning, smart cities, and the Internet of Things.

FAIRUZ ABDULLAH (Senior Member, IEEE) received the B.Eng. degree in electronics from Universiti Tenaga Nasional (UNITEN), Malaysia, in 2001, the M.Sc. degree in network and communication engineering from Universiti Putra Malaysia, in 2004, and the Ph.D. degree in fiber laser sensors from UNITEN, in 2012. He is currently an Associate Professor with the Department of Electrical and Electronics Engineering, College of Engineering, UNITEN. His research interests include optical communications, fiber lasers, optical amplifiers, and fiber optic sensors. To date, he has published more than 100 journals and conference papers. He has been an active member of the IEEE Photonic Society.

NURUL ASYIKIN MOHAMED RADZI (Senior Member, IEEE) received the B.E.E.E. (Hons.), M.E.E., and Ph.D. degrees in engineering from Universiti Tenaga Nasional (UNITEN), Malaysia, in 2008, 2010, and 2013, respectively. She is currently a Senior Lecturer with the Department of Electrical Electronics Engineering, UNITEN. She has contributed more than 50 technical papers in various journals and conferences. Her research interests include optical communication and the quality of service. She is a Professional Engineer and a Chartered Engineer of the Institution of Engineering and Technology (IET).

AYMEN DAWOOD SALMAN received the B.Sc. degree in electrical and electronic engineering and the M.Sc. degree in computer and information technology/software engineering from the University of Technology–Iraq, in 1998 and 2004, respectively, and the D.Eng. degree from the Communication Networks Group, Technical University of Ilmenau, Germany. He is currently a Senior Engineering and Telecommunications Assistant Professor with the Department of Computer Engineering, University of Technology–Iraq. His research interests include MANETs emphasizing QoS routing and mobile multimedia communication.

SAID JADID ABDULKADIR (Senior Member, IEEE) received the B.Sc. degree in computer science from Moi University, the M.Sc. degree in computer science from Universiti Teknologi Malaysia (UTM), and the Ph.D. degree in information technology from Universiti Teknologi PETRONAS (UTP). He is currently an Associate Professor and a member of the Centre for Research in Data Science (CeRDaS), UTP. He is involved in flagship consultancy projects for PETRONAS under pipeline integrity, materials corrosion, and inspection. His research interests include machine learning, deep learning architectures, optimizations, and applications in predictive analytics. He is serving as the Treasurer for the IEEE Computational Intelligence Society Malaysia Chapter and the Editor-in-Chief for *Platform* journal.